Fish Passage Assessment of Culverts Constructed to Simulate Stream Conditions on Liard River Tributaries

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by

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ABSTRACT

McKinnon, G.A., and F.N. Hnytka. 1985. Fish passage assessment of culverts constructed to simulate stream conditions on Liard River tributaries. Can. Tech. Rep. Fish. Aquat. Sci. 1255: vi + 121 p.

From 1978 to 1981 four small streams crossed by the Liard Highway were studied to assess the affects of culverts on fish. The culverts were constructed in 1979 and rock riprap was placed on the culvert floor to provide areas of low water velocity for migrating fish. Stream grade and cross-sectional dimensions were used to set culvert slope and size. This approach, named "stream simulation", attempts to simulate natural rapids that present no difficulty to migrating fish.

Flow levels in all four streams varied widely but did not exceed the mean annual flood estimated by hydrologic analysis, in any of the four years of study.

Culvert placement together with internal riprap and slope stabilization at the inlet and outlet areas were completed in stages over approximately a one year period. As a result severe erosion produced ditch gullies and added large amounts of sediment to the stream bed. This also had the effect of burying culvert riprap and in many cases rendering it ineffective in reducing culvert velocity.

Culvert riprap, when not buried by sediment, was effective in reducing culvert velocities. An added benefit was that culvert icing became suspended by culvert riprap allowing flow and, subsequently, fish migration under the ice between boulders.

The highway crossing of the streams varied from 3.7 to 5.1 km upstream of the Liard River confluence. Spawning migrations of Arctic grayling (Thymallus arcticus) and longnose sucker (Catastomus catastomus) at the highway crossing occurred in three of the four streams studied; one stream also had significant numbers of northern pike (Esox lucius). The streams in the vicinity of the highway crossing provide a mainly feeding and rearing habitat with only a small amount of spawning habitat located this distance upstream from the Liard River mainstem.

The culverts did not present a barrier to fish migration in any year of study.

Keywords: highway construction; culverts; baffles; fish passage; fish biology; stream flow; hydraulics.

RESUME

McKinnon, G.A., and F.N. Hnytka. 1985. Fish passage assessment of culverts constructed to simulate stream conditions on Liard River tributaries. Can. Tech. Rep. Fish. Aquat. Sci. 1255: vi + 121 p.

De 1978 à 1981, nous avons étudié quatre petits ruisseaux qu'enjambe l'autoroute Liard afin d'évaluer l'effet sur les poissons que produisent les ponceaux qu'on y a construits. Lesdits ponceaux furent construits en 1979, et nous avons délibérément placé des pierres concassées sur le fond des ponceaux, pour recréer les conditions d'eau peu rapide que rencontre le poisson dans sa migration. Nous y avons aussi reproduit la pente et les dimensions en coupe transversale du ruisseau. Nous avons appelé cette façon de procéder "simulation de ruisseau". Cette approche tente en effet de reproduire des rapides naturels, comme ceux qu'emprunte sans difficulté le poisson migrateur.

Le débit dans les quatre ruisseaux étudies a varié énormément au cours des quatre années d'observation, sans toutefois dépasser le débit annuel moyen calculé d'après les évaluations des analystes en hydrologie.

Les travaux de construction des ponceaux (installation des ponceaux, pose de pierres concassées, stabilisation de la pente à l'entrée et à la sortie des ponceaux) furent accomplis par étapes, et durèrent une période d'un an environ. Il en est résulté une érosion considérable qui a produit des rigoles et a répandu de bonnes couches de sédiments sur le lit des ruisseaux. Cette érosion a aussi eu pour effet de couvrir les pierres concassées sur le lit des ponceaux de sorte que, en certains cas, celles-ci ne réussirent pas à réduire la rapidité du courant.

Car nous avons constaté que les pierres concassées, lorsqu'elles ne sont pas recouvertes de sédiments, ralentissent la course des ruisseaux sous les ponceaux. Elles présentent un autre avantage: par temps froid, elles laissent passer entre elles l'eau, et les poissons en migration, sous la glace qui se forme.

Les ponceaux ont été construits sur l'autoroute Liard à des distances variant entre 3,7 à 5,1 km en amont de la confluence de la rivière Liard. Dans trois des quatre ruisseaux, nous avons observé des migrations d'ombre arctique (Thymallus arcticus) et de meuniers rouges (Catastomus catastomus) qui remontaient le cours d'eau pour frayer; et dans l'un des ruisseaux nous avons aperçu un nombre important de grands brochets (Esox lucius). Les tronçons de ruisseau avoisinant les ponceaux servent surtout de lieu où les poissons viennent s'alimenter et élever leurs petits, et où très peu d'entre eux fraient, étant donné la distance en amont qui les sépare de la rivière Liard.

Les ponceaux n'ont pas empêché la migration des poissons pendant les quatre années qu'a duré l'étude.

Mots-clés: construction d'autoroute; ponceaux; tranquilliseurs; passage de poisson; ichtyobiologie; débit de ruisseau; technologie hydraulique.

INTRODUCTION

In 1975 the then Central Region of the Fisheries and Marine Service published guidelines for protection of fish resources during highway construction and operation in the Northwest Territories (Dryden and Stein 1975). This publication has served as this region's main instrument for protecting fish and fish habitats from the potentially damaging effects of linear facility construction in the north.

A major test of the applicability of these guidelines came in the late 1970's with the proposal by the Department of Indian Affairs and Northern Development (DIAND) to complete construction and to operate an all-weather road (the Liard Highway) from the vicinity of Fort Simpson, N.W.T. to Fort Nelson, B.C., a distance of 357 km. Construction of the first 34 km was actually completed in 1972 by the Canada Department of Public Works (PWC); work was then halted until 1978 when construction began anew on the remaining portion. During the initial building phase, construction of the Poplar River Crossing created a major impairment to fish migration (Jones 1979). The Department of Fisheries and Oceans (DFO) was concerned that this not be repeated for the remainder of the highway.

Fish passage designs are, however, difficult and costly to construct and it is recognized that requests for such designs should be supported with sufficient field data to demonstrate biological need. For that reason the Fisheries and Marine Service in 1977, under funding from DIAND undertook a survey of Liard River tributaries crossed by the proposed highway alignment (McKinnon and Hnytka 1979). The objectives of the study were to provide survey information on fish resources and habitats occurring in Liard River tributaries and to make recommendations which would ensure their protection during highway construction and operation.

As a result of the study, twenty-seven streams were designated as requiring fish passage designs. Subsequent discussions between Public Works Canada and the Department of Fisheries and Oceans centered on the problem of accurately predicting stream flows for streams designated for fish passage designs.

Public Works Canada favoured use of a stream flow curve developed for use along the Mackenzie Highway by the Water Planning and Management Branch (WPM) of Environment Canada (Water Planning and Management Branch 1975). This curve was considered by WPM to represent the best estimate for preliminary design purposes at the time. The WPM guidelines, however, were not intended to substitute for hydrological and meteorological data or for use in producing final design criteria for individual stream crossings. One of their recommendations in part was "In future, as soon as a project of this nature is conceived in a remote area, attempts should be made to initiate a program for measuring stream flows and meteorological conditions. In this way, by the time the final design stage is reached, there would be some data available upon which to base estimates of design floods, water supply, etc.".

Several cases of floods close to or exceeding the WPM design flows were observed along the Mackenzie Highway in the 1970's. Jasper and Anderson (1977), and Grey and Jasper (1978) noted several problems associated with its use for Liard Highway design purposes. Because of the meteorological and geographical dissimilarity between the Mackenzie and Liard river valleys DFO was concerned. Comparison of Fort Liard and Fort Simpson precipitation records (summer months only) for the period 1974-77 revealed that the former received substantially more rainfall over the period and that there was a low correlation between the stations both for daily and monthly values. Two major ramifications of underdesign were expected to occur:

1. On those streams in which fish passage designs were not required, design to the WPM curve might result in overtopping or washout of the crossing structures with consequent effects on downstream habitat.

2. On those streams in which fish passage was required, design to the WPM curve was expected to result in velocities exceeding the fisheries guidelines since actual flows were likely to be greater than those predicted by the WPM curve.

In the fall of 1978 PWC indicated that strict adherence to the 0.9 $m \cdot s^{-1}$ velocity criterion as outlined in Dryden and Stein (1975) would not be economically viable for many crossings and requested DFO to provide alternative design approaches. Three design approaches were developed for specific stream crossings where fish passage was required throughout culverts (McKinnon and Hnytka 1979):

1. Plain culvert: Use plain pipe(s) and ensure that mean velocities through any culvert cross-section are less than 0.9 $m \cdot s^{-1}$ at or below the fish migration discharge; concentrate low flows and secure at least 20 cm of water through the culvert(s).

2. Stream simulation: Maintain natural stream properties at the crossing (i.e. average cross-section, width, slope, substrate) for flows up to the fish migration discharge, concentrate low flows, and provide within the culvert(s) a rock substrate, stable at the 1:50 year flood.

3. Culvert fishways: Design and install baffles within the culvert(s) that operate effectively at or below the fish migration discharge, and secure at least 20 cm of water through the culvert(s) during low flows.

In all three approaches allow no upstream ponding for the 1:50 year flood, avoid any significant drawdown at the inlet, outlet or within the culvert(s) and provide adequate free board.

For the proposed Liard Highway culvert stream crossings of flat and intermediate drainage basins the fish migration discharge was defined as the maximum discharge allowing fish to traverse a stream crossing. The mean annual

flood (1:2.33 years recurrence interval) was used as the fish migration discharge.

In addition to the above DFO indicated that culverts greater than 60 m in length were not recommended for fish passage (Dane 1978) and could not realistically be expected to simulate natural stream conditions without special considerations (e.g. baffles).

Early in 1979, DIAND contracted M.M. Dillon Limited to provide design guidelines on sizing of river crossings for both hydrology and fishery aspects along the highway in the N.W.T. M.M. Dillon Limited (1979) developed a regression equation based on physiographic and climatological parameters to provide estimates of the mean annual flood. In addition a dimensionless flood frequency curve was developed with which to convert the mean annual flood to the required design flood. The authors felt that "for rivers populated by fish, the sizing of the culvert openings should be based on the hydrologic design flow and the design velocity derived from fish studies. For watercourses with no fish population, or for very small drainage areas where the possible loss of spawning grounds can be tolerated, the designer should consider the effect of scouring and ice jams, when determining the required cross-sectional area".

The M.M. Dillon Limited (1979) recommended design method predicts lower flows than the WPM curve (Water Planning and Management Branch 1975) and was not used for Liard Highway design purposes, however, its use for future highway culvert design should not be precluded.

Public Works Canada in conjunction with DIAND subsequently determined that the option of maintaining natural stream properties at the culvert site was the most viable option in most cases. As part of the overall exercise, the Fisheries Habitat Section of DFO agreed, under funding by DIAND, to carry out an assessment of the "stream simulation" technique as well as to test the validity of assessments made in the 1977 survey (McKinnon and Hnytka 1979).

The Liard Highway Study was conducted over a period of four years representing pre-construction, construction and post-construction phases of highway development.

Investigations were concentrated on four small Liard River tributaries which transect the Liard highway at mileages 48.9, 50.7, 51.9 and 59.3. Each of these streams is identified by the associated highway mileage.

Pre-construction data was collected in 1978 supplemented by information obtained from the 1976/77 survey of Liard River tributaries (McKinnon and Hnytka 1979). Culvert placement within the study area began in early 1979 and was generally completed prior to freeze-up of the same year. In addition to further collection of baseline data, the 1979 program provided an opportunity to assess the immediate effects of construction activities on the study streams and to evaluate various construction practices used. The 1980 and 1981 programs were designed to provide data on post-construction impacts and to evaluate the fish passage capabilities of installed culvert structures.

The overall objectives of the assessment study were:

1. to collect pre- and post-construction data on stream hydrology, and fish species composition, habitat use, migration patterns and timing;
2. to determine the relationship between stream physical parameters and the timing of fish migrations and habitat use;
3. to monitor construction and post-construction impacts;
4. to determine the effectiveness of fish passage measures in culverts; and
5. to determine the suitability of the "stream simulation" technique.

This report presents results of the study and recommendations provided herein will aid in the formulation and upgrading of DFO guidelines for use on future linear development in the north.

STUDY AREA DESCRIPTION

The Canadian Cordillera to the west and the Interior Plains to the east comprise the two major physiographic divisions in this region. The Liard and Nahanni Ranges, both part of the Mackenzie Mountains, compose the Cordillera region with peak elevations of one to two thousand metres above sea level. The Interior Plains are made up of the more northerly Great Slave Plain and the Alberta Plateau to the south. The Liard River, which flows north from British Columbia, forms a crude boundary between the two. Near Nahanni Butte the Liard River loses contact with the mountains and swings east to join the Mackenzie River.

The Liard Highway is on the east slope of the Liard River valley (Fig. 1). During continental glaciation the Liard valley was filled with glacial deposits composed mainly of silty tills containing boulders. Following glacial retreat the Liard River traversed the glacial deposits leaving a broad band of granular alluvial deposits. The present Liard River channel has incised into the overburden of glacial till throughout most of its length.

The highway route is located mainly on glacial tills close to their contact with Liard River alluvial deposits. The glacial till is typically overlain by thin silt deposits. A large proportion of the drainage areas of streams crossing the highway are muskeg. Areas of flat slope having poor surface drainage with much ponding are common. Permafrost is discontinuous.

The drainage basin of Creek Mile 48.9 is characterized by a low gradient but has generally good channel definition. The substrate at

the alignment is composed of silt and organic material while in downstream areas there is a transition to course gravel and boulders, intersticed by alluvial material. Vegetation in the area is predominantly black spruce and aspen.

Creek Mile 50.7 and Creek Mile 51.9 follow parallel courses before converging into a common channel that discharges into the Liard River. Both streams originate on the slope of a rock scarp and then flow in contorted meandering channels across an expansive flat region characterized by black spruce bog. Beaver dams and pools alternating with small riffle areas are prominent features. The substrate is composed of organic-rich silt but small gravel areas occur in the upper reaches. The transition is to boulders and sand downstream.

Creek Mile 59.3 drains an area characterized by swamp and small intermittent lakes and empties into a highwater channel of the Liard River. The upper reaches of the stream flow in a series of small pools through an open bog area. The stream transects a well-drained area with good channel definition and a gravel-boulder substrate near the highway alignment before deepening into alluvial deposits near the mouth. Beaver dams are common throughout. Upstream areas support a black spruce bog community while aspen and white spruce, with alder and willow on the high banks are more common near the highway crossing.

METHODS AND MATERIALS

Field studies were conducted during the spring freshet of each year in an effort to monitor spring spawning migrations of fish as well as to collect relevant physical data from the individual streams. Additional surveys were conducted during the summer and fall months to provide data on seasonal habitat utilization and movements of resident fish populations as well as to document physical characteristics of the individual streams at these times.

Data was collected on both physical and biological parameters with effort made to maintain the same general sampling techniques and timetable on a yearly basis. However, physical conditions present within the streams at time of sampling frequently determined the specific methods used.

PHYSICAL PARAMETERS

Stream discharge and velocity

Prior to construction hydraulic cross-sectional stations were established at each stream in the vicinity of the proposed highway crossing. Staff gauges were installed at each of these stations and stage readings were made daily. Water velocity determinations were made with a hand-held OTT meter (model C-31-10.002) utilizing propellers of 125 mm diameter and of either 0.25 m or 0.50 m pitch for water velocities less than or greater than 1.5 $m \cdot s^{-1}$ respectively. Where water depth permitted, velocity measurements were made at 0.2, 0.4, 0.6 and 0.8 of total depth from the surface at 0.25 m horizontal intervals along a transect. At low discharges, where uniform flow characteristics were observed, the midsection method (USDI 1967) was adopted with readings taken at 0.6 of total depth at 0.5 m horizontal intervals. Water velocities were measured over a 30 second time interval with the exception of a few cases where high velocities necessitated sampling for a shorter duration. Measurements were made daily except when stage remained relatively constant.

After culvert installation hydraulic cross-section stations were established within the culverts at the inlet, outlet, and a location approximately midway between the two. At each stream, stage levels were recorded on the culvert wall at each station and later tied into a common benchmark using a Wild (model N-10) engineers level. Metric level rods were read to the nearest cm and estimated to the nearest mm. Velocity determinations were made using a full size OTT meter as previously described or a Marsh McBirney (model 201) portable electromagnetic meter. The latter meter permitted measurements in confined areas where rocks and other obstructions prevented the use of conventional meters. Velocity readings were taken at 0.2, 0.4, 0.6 and 0.8 of total depth from the surface at 0.25 m horizontal intervals. The midsection method, measuring velocity at 0.6 of total depth was again used where uniform flow conditions were observed. Velocity measurements were taken over a 30 second time interval using the conventional OTT meter whereas a minimum stabilization time of 40 seconds was used for the Marsh McBirney meter with the instrument adjusted to the 20 second time constant setting.

All measurements were collected and are presented in metric units. Discharges were calculated at all transects where no turbulent flow was observed using either the midsection method or the three point method (USDI 1967). Where more than one estimate of discharge was calculated estimates were averaged. Where all designated transects were affected by turbulent flow or when high flow conditions prevented access to the culvert stations, special discharge transects were established at more favourable sites near the highway crossing sites.

Graphical presentation of culvert cross-sections was achieved by inserting a scaled illustration within a circle, depicting the culvert structure. Key references are the centreline distance from culvert top to water level as well as the absolute stage level. Lateral compression of the actual culvert structure was responsible for the apparent distortion at the bottom of each portrayed culvert.

Isovel contours were drawn between measured velocity readings. A representative sample of velocity measurements were indicated when not encompassed by isovels. Velocity distributions were determined by expressing the calculated area between isovels as a proportion of the total cross-sectional area. All areas were directly calculated from scaled diagrams using a Hewlett Packard (model 9831) programmable computer coupled with a graphics digitizer/planimeter.

Water quality

Water temperatures were determined to 0.5°C on each sampling date using a hand held pocket thermometer. Ryan (model G) thermographs were installed in selected streams to provide a continuous temperature record during the spring period.

Suspended solids

One litre integrated water samples were collected on a periodic basis from Creek Mile 51.9 and Creek Mile 59.3 for 1979 to 1981. Upon collection samples were returned in refrigerated containers to laboratory facilities in Winnipeg for analysis. Aliquots of the sample were passed through pre-weighed 0.45 µm Whatman G.F.C. filters and desiccated. Filters were then reweighed and suspended solids concentrations in $g \cdot L^{-1}$ were calculated.

Conductivity

Conductivity was measured in situ using a Yellow Springs Instruments (Y.S.I. model 33) conductivity meter. Readings in µmhos are expressed at recorded temperature.

Dissolved oxygen

Dissolved oxygen determinations were made during the pre-freshet survey of 1979. Measurements were made in situ beneath the ice layer using a Y.S.I. (series 5700) oxygen meter, calibrated to ambient oxygen at local elevation.

BIOLOGICAL PARAMETERS

Fish collection

A number of fish collection techniques were employed with varying success over the course of the four year-program. Flow conditions present at time of sampling frequently determined the mode of sampling. Under conditions of high flow, fish collection was not feasible.

Larger fish were generally captured by means of fish fences, gillnets and angling. Small fish were collected using fry traps, seine nets, dip nets and electrofishing. A brief description of each of these sampling techniques with a discussion on their effectiveness and limitations is provided.

Fish fences: These were used to document spring spawning migration past the highway alignment. Installation occurred immediately after spring breakup. The fence design was such that only upstream moving fish were captured. Fences consisted of a 1.2 m x 1.2 m x 0.9 m box enclosed with 25 mm (1 inch) hexagonal wire mesh. Leads of the same material were extended diagonally to each bank. The entire structure was secured to driven T-rail fence posts and anchored to the stream bottom with boulders. Generally, trap checks were made twice a day and fences were cleaned on a daily basis to prevent excessive accumulation of debris.

In 1978, fish fences were operated at Creek Mile 48.9, 51.9 and 59.3. A single fence was installed near the proposed highway crossing at each of these streams. Fish data collected included identification and enumeration of fish species, removal of scale samples for aging, length and weight measurements and determination of sexual maturity. Floy tags were selectively applied to some fish. All fish were released upstream to continue their migration.

In 1979 and 1980 fish fences downstream of the culvert were operated on all streams under study. When conditions permitted, a double trap system was used with fences located upstream and downstream of culvert installations. The downstream fence permitted the initial capture of fish. Fish data was collected as previously described and all released fish were marked either through finclipping or the use of floy tags. The subsequent recovery of these fish in the upstream trap allowed for an estimate of transit time and overall transit success for individual fish. This latter system was utilized on Creek Mile 50.7 and Creek Mile 59.3 in 1979 and on Creek Mile 51.9 and Creek Mile 59.3 in 1980.

Due to the small size of some spawning Arctic grayling, the fence design utilizing 25 mm hexagonal mesh was not completely successful at detecting the entire spawning grayling population. Only Arctic grayling of fork length greater than approximately 200 mm were retained by the 25 mm mesh. Maximum observed discharge for successful operation was in the order of 1.5-2.0 $m^3 \cdot s^{-1}$.

In 1981 the use of fences was restricted to a single installation at Creek Mile 59.3. In an effort to determine the size of the smallest migrating Arctic grayling, the wire mesh size was reduced from previously used 25 mm hexagonal mesh to 13 mm (0.5 inch) square mesh, however, chronic problems with debris retention and flow resistance caused frequent washouts. No critical lower limit for fish retained by the 13 mm mesh was detected, however, fish of 125 mm in fork length were caught.

Gillnets: Multifilament gillnets of 25 mm to 55 mm stretched mesh were used extensively throughout the spring period either in conjunction with fish fences or as an alternate catch method in cases where it was not possible to install a fence. Nets were set in pools or other calm areas and checked frequently to ensure live capture of fish. Captured fish were identified, measured then released upstream.

The effectiveness of gillnets was severely limited during periods of high flow due to fast currents, heavy debris and a lack of suitably calm areas.

Gillnets were used exclusively during the summer and fall surveys and provided much information on the seasonal distribution and abundance of the various fish species.

Seine nets: A 3.7 m x 1.2 m beach seine of 6 mm (0.25 inch) mesh was used under low flow

conditions for the collection of small fish. Seines proved to be most useful in the capture of young-of-the-year Arctic grayling. Seining was confined to pools and other areas where debris was not a factor.

Dip nets: Fine mesh dip nets secured to a one metre handle were also used for the capture of small fish, particularly fry. Dip nets were useful in areas where seine sweeps were impractical and increased the catch of small fish.

Fish marking

Floy tags: Sequentially numbered floy tags were attached to some mature Arctic grayling, northern pike and longnose sucker. Tags were inserted into the left side of the fish body near the base of the dorsal fin using a Denison (model FDM-68) tagging gun. Tag recoveries provided documentation on timing of fish passage through the culverts as well as providing information on annual and seasonal movements and distribution of tagged species.

Fin clips: A small V-notch incision was made at the extremity of selected fins on Arctic grayling, longnose suckers and northern pike captured in the downstream fences. A daily coding system was achieved by designating a specific sequence of clipped fins for each day. A maximum of two fins were used in the coding sequence.

Fish treatment and analysis

Fish identification: The taxonomic keys provided by McPhail and Lindsey (1970) and Scott and Crossman (1973) were used for the identification of all fish species.

Small fish: Fish of all species which had a fork length less than approximately 100 mm were included in this group. Upon collection samples of small fish were fixed in 10% formalin then preserved in 70% ethanol and returned to laboratory facilities. Subsequent analyses included identification to species, length and weight determinations to 1 mm and 0.1 g respectively, determination of sexual maturity, and removal of otoliths for aging purposes. Stomachs from all species other than suckers were removed and analysed for content. Ingested organisms were identified to order and selected families then enumerated.

Sexual maturity determined by extent of gonadal development was assigned to both male (M) and female (F) fish in the following categories:

0 - juvenile	3 - mature
1 - immature	4 - ripe
2 - maturing	5 - spent

Large fish: Arctic grayling, northern pike and longnose sucker which had a fork length generally greater than 100 mm and were either maturing or mature were included in the group. Fish were either live or dead sampled as follows:

LIVE SAMPLE: Fork length and weight were measured to the nearest 1 mm and 10 g respectively. Fish scales were removed from the left side of the body near the base of the dorsal fin on Arctic grayling and northern pike. Sexual maturity was determined by expression of sexual products and designated as being mature, ripe, spent or indeterminate. No attempt to distinguish sexes by dimorphic characteristics was made.

Selected fish were marked either by fin clipping or Floy tags as previously described, then released. Recaptured fish were measured, recorded and again released.

DEAD SAMPLE: A small number of fish were periodically sacrificed or found dead in gill nets. Length, weight and scale samples were taken as per live sample. Sexual maturity was determined by gonadal inspection and assigned within the maturity classification previously given. Ovaries were removed from several spawning Arctic grayling and preserved in 10% formalin solution for fecundity analysis. Stomachs were removed from all dead Arctic grayling and northern pike, fixed in 10% formalin and later preserved in 70% ethanol. Identification and enumeration of ingested organisms were performed as previously described.

Aging:

OTOLITHS: were removed from all small fish and stored in glycerine. Prior to examination otoliths were transferred to a benzyl-benzoate/methyl-salicylate clearing solution. Reading was performed under reflected light using a stereo dissection microscope.

SCALES: were removed from fish, placed within manilla envelopes and allowed to dry. Scales were later mounted between opposing glass slides and annulii were interpreted using a Leitz trichinoscope. All ages are reported in terms of number of winters survived.

Fecundity: Ovaries collected in 1980 from Arctic grayling captured at Creek Mile 50.7 were analysed for total egg counts as well as average egg diameter and weight. Ovaries were preserved in a 10% formalin solution and returned to the laboratory. Prior to analysis, ovaries were flushed with water and membrane material was removed. Total egg count, mean egg diameter and weight were determined for the wetted eggs. Eggs were subsequently desiccated at 50°C for 24 hours and reweighed providing an estimate of mean dry weight.

Statistical analysis: Data analysis was performed using a Hewlett Packard 9810-A or a 9831-A programmable computer. Mean, standard deviation and range were calculated for fork length and age by sample period, species and sex. Student's T-test was used to detect significant differences in means between sexes. If no significant difference was detected then the data were pooled.

RESULTS

Data on physical and biological parameters measured over the course of the four years of study are presented in this section. It is important to bear in mind that the collection of biological data is frequently affected by the physical conditions present at the time of sampling. Temperature, precipitation and the magnitude of spring flooding often determine the relative effectiveness of sampling techniques employed. Grey and Jasper (1978) provide an overview of many of the factors which affect spring runoff and general flow regimes within the study area.

METEOROLOGICAL AND HYDROLOGICAL CONDITIONS

1978 study year

Meteorological conditions in the area at the time of the 1978 study were generally moderate. Slow and prolonged snow melt with steady runoff characterized the spring freshet. Meteorological data collected by AES (1978) from stations at Fort Simpson and Fort Liard are provided in Table 1.

Near normal conditions had prevailed during much of the previous winter. Precipitation for the period October, 1977, to May, 1978, measured at Fort Simpson totalled 110.9 mm in water equivalent or 73% of the overall normal value. Precipitation for the same period measured at Fort Liard amounted to 179.5 mm which is substantially higher than the value for Fort Simpson. Heavy precipitation in the Fort Liard region during the months of December and May accounts for much of the difference. As the Fort Liard station has only recently been established, data comparisons to normal values are not possible.

The mean overall departure of temperatures from the station norms during the same period at Fort Simpson was +0.7°C indicating temperatures only slightly above normal.

In general the data indicate a moderate winter/spring period both in terms of temperature and precipitation. Of particular interest though, are the values for precipitation during the month of May which coincide with spring runoff. The value of 4.2 mm reported from Fort Simpson is in marked contrast to 51.0 mm for Fort Liard. Although no data were available for the immediate study area, personal observations indicate that precipitation within the study area during May was likely between the two values with the only significant rainfall occurring on May 28-29. A response to this rainfall is detectable in the hydrograph for Creek Mile 59.3 only (Fig. 2). The hydrograph for the Water Survey of Canada (WSC) gauged stream closest to the study area (i.e. Birch River) is presented in Fig. 3 and shows no apparent response to a rainfall event during this time period.

1979 study year

Climatic conditions experienced during the 1979 study exemplify the dramatic effect that precipitation can produce on streamflow during spring breakup. Meteorological data collected by AES (1979) from stations located at Fort Liard and Fort Simpson are in Table 1.

Analysis of mean daily temperature data indicates consistently below normal temperatures for much of the total period with an overall departure for the station norm at Fort Simpson of -1.8°C. Temperatures reported from Fort Liard were consistently higher than those of Fort Simpson. Although the timing of precipitation varied considerably between the two stations, the overall precipitation values were similar. Precipitation of 178 mm received at Fort Simpson was 121% of the station norm. Prior to May 18, spring breakup was characterized by a gradual and protracted thaw with the hydrographs of each stream remaining relatively level. However, rainfall which occurred between May 18 and May 20 created an instant response in stream flows with ten fold increases in discharge for several of the streams under study. Precipitation data from Atmospheric Environment stations at Fort Simpson and Fort Liard for the three day period show that a total of 13.4 mm fell in Fort Simpson and 20.2 mm fell in Fort Liard.

Personal observations suggest that the Fort Simpson data are closer to the conditions experienced in the study area although it is probable that more precipitation occurred on May 19 within the study area than was the case at Fort Simpson. The only other significant rainfall during May was reported on May 26-27 at Fort Liard where 10.8 mm of precipitation fell and on May 26 when 14.2 mm of precipitation fell at Fort Simpson. An additional weather station operated by the Department of Indian and Northern Affairs, Northern Affairs program was established after May 20 near the Nahanni Butte settlement. This station reported 12.7 mm and 25.4 mm of rainfall for May 26 and 27. Nahanni Butte is located within 40 km of the study area. Precipitation within our study area occurred only on May 26 and was not believed to be as severe as at the weather stations. Only a modest response was detected in the hydrographs of the study streams (Fig. 2) and Birch River (Fig. 3) at this time whereas data collected by Water Survey of Canada for Rabbit Creek near Fort Liard (IWD 1979) show a five fold increase in discharge from 2.32 $m^3 \cdot s^{-1}$ on May 25 to 13.1 $m^3 \cdot s^{-1}$ on May 27.

Preliminary field investigations were conducted on April 5 to determine winter characteristics and possible overwintering potential of each of the streams. At this time clearing and excavation for culvert placement was underway. By May 1 construction was well in progress with culvert installations in place at three of the four study streams, the exception being Creek Mile 51.9 where instead a diversion channel was trenched around the proposed culvert site.

1980 study year

Climatic conditions and spring runoff characteristics experienced in 1980 were in marked contrast to those observed in 1979. Spring breakup was preceded by an unusually mild winter. Meteorological data collected by A.E.S. (1980) from stations at Fort Liard and Fort Simpson are provided in Table 1.

The sporadic nature of the Fort Liard data during 1980 does not permit its inclusion in any detailed analysis however it does illustrate the overall climatic trend as well as local variability in precipitation values. The consistently above normal temperatures at Fort Simpson for the period cited, as well as below normal precipitation (83.8%) were major factors which affected the spring runoff. Spring conditions were characterized by a slow and prolonged runoff with very modest flow as indicated by the Birch River hydrograph (Fig. 2). The occurrence of peak discharge on April 22 is substantially earlier than in previous years. Peak flows for the two consecutive years prior to 1980 occurred within the first two weeks of May.

Rainfall was not an important factor in determining the magnitude of flow in 1980. The Fort Simpson meteorological station reported significant rainfall (10.7 mm) on April 29, however, the discharge data from Birch River indicates only a modest increase in flow conditions at this time. Negligible precipitation fell during the first three weeks of May.

The 1980 study commenced on April 30. On the basis of the preceding discussion we conclude that peak flow conditions occurred prior to the commencement of the study. However, the lack of high water marks and channel scouring, suggests that discharges observed were not a great deal lower than peak.

1981 study year

Stream flow conditions observed in 1981 were unlike those of previous study years. High flow conditions existed as a result of rapid snowmelt. Study of meteorological data collected by AES (1981) from stations at Fort Simpson and Fort Liard for the period October 1980 to May 1981 provides some insight into the factors responsible for the spring condition observed (Table 1).

Mean monthly temperatures were 3.3°C above normal at the Fort Simpson station for the period October, 1980, to May, 1981. Similarly total precipitation for the same period was 208 mm of water equivalent or 145% of the normal amount expected. However, the majority of precipitation occurred immediately prior to snowmelt with 250% of the normally expected precipitation reported for the period February to April and with particular regard to the 63.5 mm of water equivalent reported from Fort Simpson in April which was 418% of the norm. Mild spring temperatures experienced during the latter part of April and throughout May rapidly melted accumulated snowfall and brought about high runoff conditions. This was particularly the case for Birch River where discharge increased from under 0.1 $m^3 \cdot s^{-1}$ on May 1 to a recorded maximum of 60.0 $m^3 \cdot s^{-1}$ on May 5 (Fig. 2). Peak flows were generally delayed in the streams under study until May 6 and May 7. Discharge declined steadily after peak flow with the absence of precipitation.

The 1981 study was conducted between May 2 and May 21 with the general emphasis placed on collection of physical data and evaluating culvert performance. Biological sampling was primarily conducted by means of gillnets to determine the timing schedule of fish migrations. High water conditions greatly hampered fish collection.

CREEK MILE 48.9

1978 study year

Collection of physical data began on May 8. Stream discharge during the spring period ranged from 0.51 $m^3 \cdot s^{-1}$ on May 9 to 0.05 $m^3 \cdot s^{-1}$ on June 3 (Fig. 2). The slow and prolonged snowmelt in the drainage basin together with very little precipitation during May is reflected in the hydrograph which decreases steadily from the onset of measurement in early May until June 3. Maximum recorded instantaneous velocity and mean cross-sectional velocity were 0.80 $m \cdot s^{-1}$ and 0.37 $m \cdot s^{-1}$ respectively at the maximum discharge rate of 0.51 $m^3 \cdot s^{-1}$. Cross-sectional velocity profiles in the natural stream channel at given discharge rates are presented in Fig. 4. Under the flow regime prevailing in 1978 the cross-sectional velocity distribution is skewed to the left. At the peak recorded discharge rate of .51 $m^3 \cdot s^{-1}$, 87% of the cross-sectional area is subject to water velocity of 0.60 $m \cdot s^{-1}$ or less.

Water temperatures increased from 0.5°C on May 10 to 15.0°C on June 6 (Fig. 5).

No evidence of spring spawning migrations of either Arctic grayling or longnose sucker was detected at the proposed highway crossing of Creek Mile 48.9 in 1978. However, both species had moved into the system as far as the highway crossing prior to September 20. Brook stickleback and finescale dace taken in fry traps were the only fish species caught during the period May 14 to June 4 (Table A1). Both species appeared to spawn sometime after May 23 with 53% of brook stickleback and 63% of finescale dace collected after this date reported to be in spawning condition. Mean fork length of six spawning brook stickleback was 60 mm (SD=8.9; range = 42-66 mm). Minimum age for spawning brook stickleback was 3 years. Mean fork length of nine spawning finescale dace was 64 mm (SD=9.9; range = 45-81 mm). Spawning finescale dace ranged in age from 3-5 years. Finescale dace were previously reported in spawning condition in this stream on July 11, 1977 (McKinnon and Hnytka 1979).

Stomach content analysis of brook stickleback and finescale dace are provided in Table 2. Chironomid larvae comprised the most important dietary component of the former and Plecoptera that of the latter.

Three Arctic grayling and one longnose sucker were collected in gillnets set during the fall survey. The presence of these fish at this time indicates that post-spawning feeding movements occur in this stream as neither of these species were detected during the spring survey. Fork length of the Arctic grayling ranged from 187-217 mm with ages assigned to the 1 and 2 year classes (Table A2). Fork length of the longnose sucker was 152 mm.

Individual fish data for all species caught in 1978 are included in Table A3.

1979 study year

The initial prespring survey at Creek Mile 48.9 was conducted on April 5 at which time the stream was completely frozen with no detectable flow. A single 5.2 m structural plate corrugated steel pipe (S.P.C.S.P.) culvert was installed before May 1. Technical data and the site plans of the culvert installation as provided by PWC are included in Fig. 6. Riprapping and cleanup measures were not undertaken during the spring period (Photo 1).

Stream discharge measured during the spring period ranged from 0.28 $m^3 \cdot s^{-1}$ on May 4 to 1.75 $m^3 \cdot s^{-1}$ recorded on May 21 (Fig. 2). Maximum flow conditions however, probably occurred between May 18 and May 21 when the stream was inaccessible. Considerable fluctuation in water temperature was apparent during the spring period and ranged from 0.0°C on May 8 to 10.0°C on June 2 (Fig. 5).

Mid-day water temperatures recorded for other sampling periods include 17.0°C on July 10, 15.0-14.0°C on August 19 and 20, and 9.5-9.0°C on September 8 and 9. The combination of rainfall on exposed slopes and high water flow in unprotected channels, contributed to heavy additions of silt into the stream. Silt deposits remained after spring flows receded and were still in evidence during the fall survey. Discharge measured during the fall survey was 0.02 $m^3 \cdot s^{-1}$ with mid-day water temperatures ranging from 9.0-9.5°C.

The operation of a fish fence was not successful in 1979 due to initially unstable substrate conditions within the channel followed by inundation by high water. Information collected over the spring period was on the basis of sporadic gillnet sets. One longnose sucker was caught in a gill net at the highway crossing on June 4 and was the only spring spawning fish detected.

Immature Arctic grayling, however, were captured after May 25. Three of these grayling were captured between May 25 and June 1 with fork length ranging from 180-186 mm. By late summer observations of immature Arctic grayling were frequent and three were captured on August 20. Fork lengths for these age 2 fish ranged from 191-199 mm (Table A2).

High water levels experienced during the spring period drastically reduced the numbers of small fish collected. One immature brook stickleback was taken during the spring period. Spawning populations of finescale dace and brook stickleback reported in the previous year were undetected during the spring program. Brook stickleback, young-of-the-year longnose sucker and a single lake chub, however, were captured during the August and September surveys. Mean fork length reported for young-of-the-year longnose sucker was; 40 mm (SD=2.8; range = 36-45 mm) for 11 fish collected on August 20 and 45mm (SD=2.8; range = 42-52 mm) for 12 fish collected in September.

Individual fish data for all species caught are in Table A3. Of particular interest is the absence of finescale dace from the 1979 catch.

A summary of stomach content analysis for Arctic grayling is provided in Table 3. Diptera larvae and Odonata were major food items found during the spring program whereas the terrestrial insects Hemiptera and Hymenoptera were common in samples collected during late summer.

1980 study year

Maximum stream discharge recorded was 0.11 $m^3 \cdot s^{-1}$ measured on May 1. After this date flow decreased steadily reaching a low of 0.01 $m^3 \cdot s^{-1}$ on May 19 (Fig. 2). Maximum mean cross-sectional velocity recorded was 0.52 $m \cdot s^{-1}$ at 0.05 $m^3 \cdot s^{-1}$ on May 7 (Fig. 7). Mean cross-sectional velocity was consistently higher at the culvert inlet than at the other two stations.

Recorded water temperatures rose steadily from 2.0°C on May 1 to a maximum of 11.0°C on May 16 (Fig. 5). Mid-day water temperatures measured over the course of the summer were 16.5-17.0°C in July, 11.0°C in August and 7.5-5.5°C in September. Individual point velocity measurements are provided in Table A4.

Erosion of roadside slopes was again apparent in 1980. Substantial silt accumulations were evident within the stream both locally and in downstream areas. Even a small amount of rainfall triggered a substantial erosion. Low flow conditions experienced throughout the summer were incapable of removing the added silt load.

One male Arctic grayling in spawning condition with a fork length of 190 mm was captured at the highway crossing on May 12. Mean cross-sectional velocities in the culvert on May 13 were between 0.03 $m \cdot s^{-1}$ and 0.33 $m \cdot s^{-1}$. One immature grayling and one lake chub were captured on or after May 19. A summary of growth in length data for Arctic grayling by sample period is provided in Table A2.

No fish were caught in gillnets set during the summer or fall surveys, however, young-of-the-year brook stickleback and young-of-the-year longnose suckers were taken from fry traps during the same period. Mean fork length of nine young-of-the-year brook stickleback collected on July 14 was 17 mm (SD=1.9; range = 14-20 mm); for 15 collected on August 18 it was 24 mm (SD=4.5; range = 17-35 mm). Individual fish data are in Table A3.

Analysis of stomach contents from two Arctic grayling indicates both larval and adult forms of Diptera as major food sources (Table 4). Analysis of stomach content from brook stickleback shows that Copepoda, Ostracoda and Chironomidae larvae were the major food items utilized (Table 5).

1981 study year

Stream discharge during the 1981 spring program ranged from 0.21 $m^3 \cdot s^{-1}$ on May 3 to a

maximum of 2.38 $m^3 \cdot s^{-1}$ on May 6 (Fig. 2). Maximum mean cross-sectional velocity was measured at 1.39 $m \cdot s^{-1}$ at the culvert inlet on May 6 at a discharge rate of 2.38 $m^3 \cdot s^{-1}$ (Fig. 8). At the same time, mean cross-sectional velocity measured at the culvert outlet was 0.94 $m \cdot s^{-1}$. Individual point velocity measurements are provided in Table A5. Mean cross-sectional velocity at given discharge was consistently higher on the ascending limb of the hydrograph than was the case on the descending limb. Substrate throughout the culvert at this time consisted mainly of ice overlaying granular materials. Mean cross-sectional velocities continued to decline steadily to a recorded minimum of 0.25 $m \cdot s^{-1}$ at a discharge rate of 0.75 $m^3 \cdot s^{-1}$ on May 14.

Water temperatures rose steadily from 0.5°C on May 5 to a maximum of 12.0°C on May 20 (Fig. 5). Erosion was a problem in 1981, occurring primarily along adjacent roadside slopes which discharge directly into the stream. Previous efforts to control the slope erosion with rock ditch checks proved to be ineffective. Crude wooden ditch checks were in place during the spring of 1981, however they appeared to have little effect in deterring erosion (Photo 2, 3).

Biological sampling started at Creek Mile 48.9 on May 9 and was restricted to the sporadic use of gillnets and fry traps. Two Arctic grayling were captured in gillnets set upstream of the culvert on May 15 and May 20 (Fig. 5). Both fish were sexually mature with fork lengths of 236 mm and 283 mm for age 3 and age 5 fish respectively. On May 14, 95.8% of cross-sectional area at the inlet had velocity $\leq$ 0.60 $m \cdot s^{-1}$; at the mid-culvert and at the outlet this value was 100% (Fig. 9). One of these Arctic grayling was a tag recapture, initially marked at Creek Mile 51.9 on May 8, 1980 at age 4 (Table 6). This individual had a net gain of 13 mm fork length and 42 g in weight over the period.

Two brook stickleback taken in a fry trap on May 20 were the only other fish caught during the spring program (Table A3).

CREEK MILE 50.7

1978 study year

Stream discharge for the spring period ranged from 1.00 $m^3 \cdot s^{-1}$ on May 9 to 0.08 $m^3 \cdot s^{-1}$ m on June 5. As was the case with Creek Mile 48.9 the hydrograph for Creek Mile 50.7 decreased steadily over the period (Fig. 2).

Maximum recorded instantaneous velocity of 0.47 $m \cdot s^{-1}$ occurred at a discharge rate of 1.00 $m^3 \cdot s^{-1}$ with a corresponding mean cross-sectional velocity of 0.38 $m \cdot s^{-1}$ (Fig. 10). Natural stream velocities at the discharge rates encountered in 1978 are low; 100% of the cross-sectional area at the peak discharge of 1.00 $m^3 \cdot s^{-1}$, was flowing at a rate of $\leq$ 0.50 $m \cdot s^{-1}$. Similarly on May 19, which was the only date on which sexually mature prespawning Arctic grayling were captured, 100% of the cross-sectional area of the natural channel at the highway crossing site was flowing at a rate $\leq$ 0.40 $m \cdot s^{-1}$.

Water temperature during the spring period rose steadily from 1.0°C on May 10 to a maximum of 14.0°C on June 4 (Fig. 11). Biological sampling began on May 9 at Creek Mile 50.7 with gillnets set near the right-of-way. Sexually mature Arctic grayling were first found on May 19 at a water temperature of 8.0°C and continued to appear in gillnet catches as late as June 6, however, gonadal inspection showed that all mature fish caught after May 19 were in a spent condition.

It seems apparent that the highway alignment on Creek Mile 50.7 was out of migratory range for most spawning Arctic grayling and longnose sucker in 1978. It may be that low water levels produced physical obstructions to fish in downstream locations and caused delays. Only five Arctic grayling were still in a ripe condition upon reaching the highway right of way in 1978. A total of 39 large Arctic grayling were captured at the highway crossing with 27 of 28 sexed fish being mature. Mean fork length of 11 female spawning Arctic grayling was 234 mm (SD=24.1; range = 199-282 mm), whereas mean fork length for 16 male spawning Arctic grayling was significantly higher (α=0.05) at 255 mm (SD=25.9; range = 215-297 mm). Mean age for 24 spawning Arctic grayling was calculated at 3.7 years (SD=0.67; range = 3-5 yr). No significant difference (α=0.05) in mean age between sexes was detected. Coded floy tags were attached to 10 grayling between May 29 and June 8. Subsequent recovery and observation of these fish indicated that little movement occurred during this time frame.

One mature longnose sucker and one immature white sucker were captured on May 31. Recorded fork lengths for these fish were 313 mm and 247 mm respectively.

Although not detected within Creek Mile 50.7, northern pike were captured at the confluence with Creek Mile 51.9. These fish are included in the data for the latter stream.

Numerous one-year old Arctic grayling and longnose sucker were observed on or after May 31. Mean fork length calculated for 48 Arctic grayling yearlings captured on May 31 was 80 mm (SD=9.2; range = 65-105 mm). Similarly, mean fork length for 39 longnose sucker yearlings collected on June 3 and June 8 was at 34 mm (SD=2.3; range = 29-41 mm).

It was not possible to fully document the extent of spawning migrations past the highway crossing point in 1978 as only gillnets were used. The abundance of juvenile Arctic grayling and longnose sucker in the stream indicate an important role for Creek Mile 50.7 as nursery habitat.

Seven brook stickleback and one lake chub were also caught during the spring survey. Both species were in spawning condition. Mean fork length for five spawning stickleback was 54 mm (SD=6.6; range = 49-65 mm). Fork length of the spawning lake chub was 67 mm.

Physical parameters measured during the fall survey include a stream discharge of 0.01

$m^3 \cdot s^{-1}$ on September 22 and water temperatures ranging from 4.5-5.5°C.

Arctic grayling ranging from young-of-the-year to age two fish were haptured during the fall survey. Mean fork lengths calculated for these fish were 129 mm (SD=11.0; range = 115-140 mm for five age 1 Arctic grayling, and 192 mm (SD=17.9; range = 175-217 mm) for five age 2 Arctic grayling. One young-of-the-year Arctic grayling caught at this time was 63 mm in length. A growth in length summary by age class and sample period for all Arctic grayling caught in 1978 is provided in Table A6. A single slimy sculpin completed the fall catch. Individual fish data for all species caught are included in Table A7.

Diptera larvae were the dominant food item ingested by Arctic grayling (Table 7). There was a sharp reduction in the mean number of organisms per stomach during the fall sampling period indicating light feeding at this time.

Stomach content analysis for brook stickleback by sample period and length class is included in Table 2. Diptera larvae and Plecoptera nymphs were the dominant food items found in stomachs examined.

1979 study year

On April 5, Creek Mile 50.7 was completely frozen and right-of-way clearing and instream excavation were in progress. Installation of a 4.6 m S.P.C.S.P. culvert was in place by May 1. Riprapping and cleanup were not completed at this time however (Photo 4). Technical data and the site plans as provided by D.P.W. are included in Fig. 12.

Stream discharge measured during the spring period ranged from 0.35 $m^3 \ s^{-1}$ on May 9 to 6.80 $m^3 \cdot s^{-1}$ on May 19 (Fig. 2). Mean cross sectional velocities calculated for the natural stream channel upstream of the culvert ranged from 0.15 $m \cdot s^{-1}$ at a flow rate of 0.42 $m^3 \cdot s^{-1}$ to 0.70 $m \cdot s^{-1}$ at 0.90 $m^3 \cdot s^{-1}$. The mean cross-sectional velocity at the culvert inlet was 0.70 $m \cdot s^{-1}$ when flow was 6.80 $m^3 \cdot s^{-1}$.

Surface runoff from exposed roadside slopes as well as scouring of the unprotected channel contributed to heavy instream silt addition. Silt accumulations were particularly prominent once flows had receded and were still evident during the fall survey. Installation of channel riprap and slope checks began in late summer but was not completed prior to the fall survey. Discharge measured on September 8 was 0.02 $m^3 \cdot s^{-1}$.

Water temperatures measured during the spring survey ranged from 0°C on May 8 to 11.0°C on June 2 (Fig. 11). Mid-day water temperatures recorded for other sampling periods include 17.0°C on July 10, 13.0-14.0°C on August 19 and 20, and 9.5-9.0°C on September 8 and 9.

Spawning Arctic grayling first appeared on May 17 at the counting fence erected downstream of the culvert installation (Fig. 11). Three of five fish caught on this date were tagged and released immediately upstream. By the following day, May 18, four more Arctic grayling were captured in the downstream fence and the two Arctic grayling tagged on the previous day were recovered in the upstream trap. The fence was inundated by water on May 18 and biological information was not collected from May 18 to May 20. A limited sampling program began on May 21 utilizing gillnets. Gillnet catches after this date consisted primarily of spawning longnose sucker with only a single Arctic grayling taken on May 23. In total, 10 Arctic grayling were captured during the spring period. Mean fork length for these migrants was 270 mm (SD=42.3) ranging from 222-340 mm. Mean age calculated for 10 spawning Arctic grayling was 4.1 years (SD=1.0; range = 3-6 yr).

Seventeen spawning longnose sucker were caught in gillnets between May 22 and June 2. Mean fork lengths calculated for spawning longnose sucker were 353 mm (SD=12.4; range = 340-369 mm) for nine females and 325 mm (SD=18.2; range = 302-344 mm) for eight males.

None of the longnose sucker were reported in spent condition, probably indicating that these fish were spawning at an upstream location distant from the highway crossing.

Resident Arctic grayling were captured in gillnets during both the August and September surveys. Observations of immature grayling were made during the July survey, however, gillnetting effort failed to yield samples. Two-year old Arctic grayling were dominant among the fish caught. Mean fork length for seven age 2 fish was 176 mm (SD=5.2) ranging from 167-183 mm. A single age 1 Arctic grayling with fork length of 133 mm, caught during September accounts for the remainder of the gillnet catch. One young-of-the-year Arctic grayling, 64 mm fork length, was taken in a fry trap also during the September survey. The appearance of the latter suggests that in spite of flood conditions present during the spring period, some successful spawning of Arctic grayling did occur in 1979. A summary of growth-in-length data for Arctic grayling by sample period is provided in Table A6.

Observations of young-of-the-year longnose sucker were made during each of the post-spring periods, however, only three fish were collected from fry traps during the August and September surveys. Small sample size limits analysis to reporting a fork length range of 40-45 mm for young-of-the-year longnose sucker during this period. Individual fish data for all species caught is included in Table A7.

Stomach content analysis from Arctic grayling by length class and sample period is presented in Table 3. All samples analyzed were collected during the August and September surveys at which time the diet of Arctic grayling appeared quite diverse, however, Diptera adults were consistently among the major food items ingested.

1980 study year

Cleanup of the construction zone and riprapping of the stream channel were completed prior to commencement of the 1980 spring survey. Discharge measured over the course of the

spring survey ranged from 0.08 $m^3 \cdot s^{-1}$ on May 1 and declined steadily thereafter reaching a recorded low of 0.01 $m^3 \cdot s^{-1}$ on May 19 (Fig. 2). Maximum mean cross-sectional velocity of 0.31 $m \cdot s^{-1}$ was measured at the culvert inlet on May 1 at a discharge rate of 0.08 $m^3 \cdot s^{-1}$ (Fig. 13). The relationship of point cross-sectional velocity to discharge for each of the culvert stations is provided in Table A8. Mean cross-sectional velocities were consistently higher at the inlet station.

Water temperatures recorded over the spring period in 1930 rose steadily from 0.5°C on May 1 to a maximum of 9.5°C measured on May 15, and remained relatively constant to the conclusion of the spring survey (Fig. 11). Water temperatures recorded after the spring survey included 11.5-11.0°C for July 13-14, 12.0°C for August 18 and 7.0-5.5°C for September 16-17.

The substrate within the culvert and throughout the construction zone during the spring period consisted primarily of silt materials. Low flow conditions prevailed throughout the summer with periodic precipitation maintaining minimal discharge. Rainfall was also noted to contribute to serious erosion of roadside slopes (Photo 5) with heavy accumulations of silt in stream (Photo 6). Low flow conditions were incapable of transporting all the silt materials entering the stream system and as a result this condition persisted throughout the course of the 1980 study year.

Arctic grayling was the only species of fish found to ascend Creek Mile 50.7 as far as the highway crossing during the spring survey of 1980 (Fig. 11). Spawning Arctic grayling were initially captured on May 10 and continued to appear until May 16. However, no ripe individuals were found after May 14. Mean cross-sectional velocities in the culvert varied from 0.02-0.15 $m \cdot s^{-1}$ on May 13. A total of 39 Arctic grayling were captured at the highway crossing between May 10 and May 22. Overall mean fork length of 39 Arctic grayling migrants caught during the spring survey was 193 mm (SD=27.5; range = 115-294 mm). Mean fork length of 21 known spawners was 206 mm (SD=27.4; range = 175-294 mm). No significant difference ($\alpha = 0.05$) was detected in mean fork length between sexes. Ages reported for fish caught ranged from 2-5 years although the youngest spawning Arctic grayling were reported from the age 3 class.

A total of six Arctic grayling were marked downstream of the culvert structure between May 10 and May 12. Subsequently all fish were recovered upstream of the culvert within 24 hours of their initial capture.

Resident Arctic grayling were caught during both the July and September surveys. Fork lengths for six of these fish ranged from 203-299 mm with corresponding age range of 2-5 years. Two age 5 fish tagged on May 10 and both subsequently recaptured on September 18 had growth of 5 and 9 mm respectively in fork length and 25 and 33 g respectively in weight (Table 6). A summary of growth in length data for Arctic grayling by sample period is included in Table A6.

Other fish caught during the September survey included a sample of twelve northern redbelly dace and one lake chub. Fork lengths for the above fish were recorded as 22-34 mm for the dace and 27 mm for the lake chub (Table A7).

The diet of Arctic grayling caught during the spring period consisted primarily of adult and larval Diptera whereas fish caught during later surveys displayed a more diverse diet which included Trichoptera, Coleoptera, Odonata, and fish remains (Table 4). Mean number of organisms per stomach was much greater during the spring survey indicating intensive feeding at this time.

Fecundity measurements were made on four spawning Arctic grayling under 200 mm in fork length caught between May 11 and May 15 (Table 8). The mean number of ova per female was 912 (range = 649-1433). All Arctic grayling analysed for fecundity were age 3.

1981 study year

Stream discharge recorded at Creek Mile 50.7 during the spring period ranged from a low of 0.36 $m^3 \cdot s^{-1}$ on May 3 to a maximum of 5.36 $m^3 \cdot s^{-1}$ on May 6 (Fig. 2). Maximum mean cross-sectional velocities of 1.95 $m \cdot s^{-1}$ and 1.84 $m \cdot s^{-1}$ for the culvert inlet and outlet respectively occurred on May 4 at a discharge rate of 4.16 $m^3 \cdot s^{-1}$ (Fig. 14). The corresponding velocity distributions for each station are presented in Fig. 15. Mean cross-sectional velocities measured at the peak discharge of 5.36 $m^3 \cdot s^{-1}$ were 1.61 $m \cdot s^{-1}$ at the inlet and 1.80 $m \cdot s^{-1}$ at the outlet.

Substrate at all transects initially consisted of ice-rich silt materials, however, once high flows removed these, a gravel/boulder bottom at the inlet and outlet transects and a sorted gravel/silt substrate at the midsection were exposed.

At peak discharge, flow was not confined to the stream channel as constructed but rather was spread out above the embankments converging at the culvert. Substantial erosion appeared to occur on the unprotected and unvegetated embankments (Photo 7, 8). Erosion of roadside slopes was not pronounced during the spring of 1981 probably because soils were frozen when the majority of runoff occurred.

Water temperatures ranged from 0.5°C on May 4 to 12.0°C on May 20 (Fig. 11).

Gillnets were set near the highway crossing between May 8 and May 20. Both Arctic grayling and longnose sucker in spawning condition were caught in upstream gillnets after May 16. Arrival of the first fish coincided with a discharge rate of 0.74 $m^3 \cdot s^{-1}$. Corresponding mean cross-sectional velocities at that time ranged from 0.15 $m \cdot s^{-1}$ at the midculvert transect to 0.31 $m \cdot s^{-1}$ at the culvert inlet and outlet. One hundred percent of velocities measured in the culvert at this time were <0.60 $m \cdot s^{-1}$ (Fig. 15, Table A9). No apparent delay in fish passage was observed. In total, nine Arctic grayling and four longnose suckers were caught between

May 16 and the end of the survey on May 20 (Fig. 11).

Fork length of six spawning Arctic grayling ranged from 163-323 mm with ages from three to four years. Fork length for longnose sucker ranged from 314-374 mm. One longnose sucker, previously tagged at this stream on May 25, 1979, was recaptured on May 19, 1981 (Table 6). This fish had a net gain of 5 mm in fork length and 60 g in weight over the two year period. Growth in length data for Arctic grayling by study year and sample period are in Table A6. Individual fish information for all species is in Table A7.

CREEK MILE 51.9

1978 study year

Stream discharge measured during the spring program ranged from 1.55 $m^3 \cdot s^{-1}$ on May 9 to 0.26 $m^3 \cdot s^{-1}$ on June 5 and was 0.05 $m^3 s^{-1}$ on September 23. The 1978 spring hydrograph for Creek Mile 51.9 is included in Fig. 2. Corresponding current velocities were low. Maximum instantaneous velocity of 0.51 $m \cdot s^{-1}$ was recorded at a discharge rate of 1.55 $m^3 \cdot s^{-1}$ with a corresponding mean cross-sectional velocity of 0.31 $m \cdot s^{-1}$. Cross-sectional velocity profiles at given discharge rate are presented in Fig. 16.

Water temperatures increased steadily from 1.0°C on May 10 to 15.0°C on June 4. A daily record of measured water temperatures is provided in Fig. 17 along with calendar catch frequency data for Arctic grayling, longnose sucker and northern pike.

Arctic grayling, longnose sucker and northern pike were initially captured near the proposed highway crossing on May 14 at a water temperature of 4.5°C. From May 15 to June 7 a total of 154 longnose sucker, 29 Arctic grayling, 24 northern pike and one white sucker migrated past the site. The vast majority of these fish were in spawning condition. However, as was the case with Creek Mile 50.7, few Arctic grayling reached the highway right-of-way in ripe condition in 1978. Spawners of each species were reported entirely spent after the following dates: May 17 for Arctic grayling, May 23 for northern pike, and June 1 for longnose suckers.

Mean fork length of 22 ripe or spent Arctic grayling was 254 mm (SD=33.2; range = 200-333 mm). Corresponding ages ranged from 3-5 years with a mean age of 3.7 years (SD=0.7). No significant difference (α=.05) was detected in mean fork length or age betwen sexes.

Mean fork length of 63 spawning female longnose sucker was 339 mm (SD=19.1; range = 284-368 mm) whereas mean fork length of 90 spawning males was significantly shorter (α=.05) at 317 (SD=26.0; range = 246-386 mm).

Mean fork length for 19 spawning northern pike was 441 mm (SD=73.1) ranging from 314-550 mm. Similarly mean age for 18 spawning northern pike was 4.6 years (SD=1.7) ranging from 3-8 years.

Juvenile fish caught between June 5 and June 7 included one-year old Arctic grayling and longnose sucker. Fork length ranged from 69-78 mm for five Arctic grayling and from 36-65 mm for five longnose sucker.

During the fall survey of September 20-24 water temperature and discharge were 5.0°C and 0.05 $m^3 \cdot s^{-1}$ respectively. Twenty Arctic grayling and four northern pike were caught in gillnets at this time. Arctic grayling ranged in fork length from 128-309 mm (mean 210 mm, SD=42.2). Reported ages ranged from 1-5 years with age 2 fish accounting for 70% of the catch. Mean fork length for 14 age 2 fish was 196 mm (SD=21.7; range = 168-238 mm). Northern pike caught were all 2 years old and ranged in fork length from 217-291 mm (mean 249 mm, SD=31.0).

Young-of-the-year and juvenile Arctic grayling and young-of-the-year longnose sucker were collected in fry traps during the fall. Mean fork length for three young-of-the-year grayling was 72 mm (SD=5.6; range = 67-78 mm) while mean fork length for two age 1 Arctic grayling was 131 mm (SD=22.6; range = 115-147 mm. Mean fork length of 64 young-of-the-year longnose sucker was 41 mm (SD=6.4; range = 29-74 mm).

A sample of 57 slimy sculpin ranging from 34-119 mm in total length were also collected at this time. The age distribution for these sculpins included all age classes from young-of-the-year to age five.

A growth in length summary by age class and sample period for all grayling caught at Creek Mile 51.9 in 1978 is included in Table A10. Individual fish data for all species caught are provided in Table A11.

Diptera larvae were the most abundant food item found in the stomachs of Arctic grayling of fork length under 100 mm (Table 9). The diet of fish greater than 100 mm in fork length was more diverse and included many terrestial insects. Mean number of organisms per stomach was consistently lower for the fall survey in all Arctic grayling.

Diptera larvae, particularly Chironomidae, were the most abundant food item identified in stomachs of slimy sculpin of total length under 50 mm, whereas larval forms of Trichoptera were the most frequently found item within the larger length classes (Table 2).

1979 study year

When the preliminary survey was conducted on April 5, only right-of-way clearing was completed in the area of Creek Mile 51.9. Water was detected approximately 1 m below the ice surface in a beaver pond situated at the proposed culvert site. Measurements of water quality included a dissolved oxygen reading of 0.7 $mg \cdot L^{-1}$ and a conductivity of 450 µmhos at a water temperature of 0.5°C. The odour of hydrogen sulphide was present. On the basis of the anaerobic conditions indicated it appears highly unlikely that overwintering of fish occurs in this stream.

At the start of the spring survey installation of the proposed culvert had not begun. Instead, a diversion channel and a temporary 1.2 m culvert were installed.

Stream discharge at Creek Mile 51.9 ranged from 0.59 $m^3 \cdot s^{-1}$ on May 6 to a maximum of 9.40 $m \cdot s^{-1}$ during flood conditions on May 20. The 1979 hydrograph for Creek Mile 51.9 can be found in Fig. 2.

Maximum water velocities measured within the temporary culvert were in excess of 3.0 $m \cdot s^{-1}$ at a discharge rate of 2.75 $m^3 \cdot s^{-1}$ on May 18. Washout of the culvert and roadway followed with extensive flooding throughout the construction zone (Photo 9, 10). A log bridge was subsequently built by May 22 to facilitate stream crossing until water levels receded. This structure collapsed on June 2 and a 1.2 m culvert was again installed (Photo 11).

Suspended solids concentrations were measured above and below the construction zone for comparative purposes (Table 10). Values for suspended solids concentrations were roughly three times higher in downstream locations as compared to upstream locations during high flow and were as much as 19 times higher when flood waters receded. Maximum levels of suspended solids occurred concurrently for upstream and downstream locations at peak discharge. Water quality improvement occurred at a faster rate at upstream locations than was the case downstream. Installation of the permanent culvert structure, a 4.9 m S.P.C.S.P. began in mid-July and was completed by the time of the August survey. Technical data as provided by PWC are presented in Fig. 18. Riprapping and cleanup were well advanced by the September survey and were completed before the 1980 freshet.

Water temperatures recorded during the spring period ranged from 0°C on May 8 to 13.0°C on June 1 (Fig. 17). Water temperatures recorded from the other sample periods included 17.0-18.0°C for July 10 and 11, 13.0-14.0°C for August 19 and 20 and 9.5°C reported on September 8 and 9.

A single spawning Arctic grayling was captured in the downstream fence on May 17 (Fig. 17). On May 18 flooding prevented further use of the trap and sampling was subsequently done by gillnetting. High water velocities and the heavy debris load encountered during high flow severely limited catches. Spawning longnose sucker and northern pike were first caught on May 23 and May 26 respectively. In total, three Arctic grayling, nine longnose sucker and two northern pike were caught at the highway crossing during the spring survey. Fish length ranges reported for the various species were 174-367 mm for Arctic grayling, 292-438 mm for longnose sucker and 633-665 mm for northern pike.

Resident Arctic grayling were captured during both the August and September surveys. All but one fish caught during the August survey belonged to the 3 and 4 year age classes. Mean fork lengths determined at this time were 232 mm (SD=3.8; range = 226-234 mm) for four age 3 fish, and 258 mm (SD=1.4; range = 257-259 mm) for two age 4 fish. Mean fork length calculated for six age 2 fish caught during September was 193 mm (SD=10.0; range = 183-212 mm). Fork lengths of 56 mm and 257 mm were recorded for the young-of-the-year and age 3 Arctic grayling respectively. A summary of growth in length data for Arctic grayling by sample period is provided in Table A10.

Eight longnose sucker were taken in a gillnet during the September survey. Since all of these fish were caught on the last day of the survey emigration is suggested. Fork lengths of these fish ranged from 161-188 mm which would indicate they were not part of the spring spawning migration.

Juvenile fish were caught regularly during both the summer and fall surveys. Age 1 longnose sucker ranging in fork length from 46-55 mm were captured during the July survey. One young-of-the-year longnose sucker and one young-of-the-year Arctic grayling taken in the August survey, measured 32 mm and 48 mm respectively. Young-of-the-year longnose sucker and Arctic grayling as well as juvenile longnose sucker and northern pike were observed during the fall survey. Mean fork lengths for young-of-the-year fish were 33 mm (SD=5.3; range = 27-43 mm) for nine suckers and 49 mm (SD = 9.9; range = 42-56 mm) for two grayling. One age 2 longnose sucker was measured at 116 mm in fork length. Two one-year old northern pike were 145 mm and 150 mm in fork length. The occurrence of young-of-the-year longnose sucker and Arctic grayling indicates that at least some successful spawning occurred in 1979. Individual fish data for all species caught are in Table A11.

Stomach content analysis of Arctic grayling by length class and sample period is provided in Table 11 and the large number of taxa identified indicates opportunistic feeding habits.

The extent of spawning migrations past the highway alignment at Creek Mile 51.9 were not fully documented in 1979 although individuals of each species were identified. The effects of high suspended solids concentrations and the deposition of silt downstream of the highway alignment on the overall productivity of the stream as well as the direct and indirect effects on fish populations are not known.

1980 study year

Riprapping and cleanup within the construction zone were completed before the spring survey in 1980 (Photo 12). The maximum discharge recorded for Creek Mile 51.9 during the spring survey was 0.22 $m^3 \cdot s^{-1}$ on May 1. Lack of precipitation and little snowmelt resulted in the steady decline of discharge to a recorded low of 0.06 $m^3 \cdot s^{-1}$ by May 19 (Fig. 2). On May 4 measured mean cross-sectional velocities in the culvert varied from 0.07-0.14 $m \cdot s^{-1}$ and were reduced subsequently to vary from 0.02-0.04 $m \cdot s^{-1}$ on May 13. Substrate conditions identified within the culvert during the spring period consisted primarily of silt and sand materials. Mean cross-sectional velocities were consistently higher for the culvert inlet than at the other two stations (Fig. 19). Point velocity measurements at the culvert cross-sections are provided in Table A12.

Water temperatures recorded over the course of the spring period rose steadily from 1.0°C on May 1 to a maximum of 12.5°C on May 16 (Fig. 17). Water temperatures recorded after the spring survey included 14.5°C on July 13 - 14, 12.0°C on August 17 and 7.5-6.0°C for September 16-18.

Evidence of roadside erosion into the stream was pronounced particularly during mid-summer. Rainfall, even in modest amounts, was found to readily erode the soft silt materials and deposit them into the stream. See Table 10 for suspended solids analysis for upstream and downstream locations. The downstream location yielded consistently higher levels of suspended solids with the maximum differential occurring on September 16 when a 49 fold difference in suspended solids was observed between the two stations. This extreme condition resulted from rainfall, the effects of which are described under "Meteorological and Hydrological Conditions."

Substrate within the culvert consisted of a sand/silt mixture during each of the sample periods. Riprap and other granular materials placed within the culvert as part of the design criteria were obscured by the overlying sediments. Riprap materials were still not in evidence at the water/substrate interface by the fall survey.

Spawning migrations of Arctic grayling, longnose sucker and northern pike were again documented in 1980 (Fig. 17). Spawning was first reported for Arctic grayling on May 4 and was considered complete by May 15. Nonspawning fish were also detected among the migrating population, particularly during the later stages of the run. Mean fork length calculated for spawning Arctic grayling was 238 mm (SD=35.1) for 20 males ranging from 185-306 mm and was significantly higher (α= .05) at 267 mm (SD=42.2) for 21 females (range = 190-333 mm). Similarly mean ages reported were 3.7 years (SD=0.8) for males ranging from 3-5 years and 4.5 years (SD=1.1) for females ranging from 3-6 years.

Overall, 92 Arctic grayling are known to have migrated past the highway and through the culvert between May 4 and May 20. It is probable, however, that some fish of fork length less than 200 mm may have passed undetected as these fish were able to pass through the fence. Small mesh gillnets were employed after May 11 to alleviate the problem. The overall mean fork length for all 92 Arctic grayling caught during the spring program was 227 mm (SD=41.5; range = 169-333 mm). Mean age for 88 of these fish was 3.6 years (SD=0.9; range = 2-6 yr).

Recapture of marked Arctic grayling in the upstream capture devices, indicated a 100% success rate in ability to pass through the culvert structure. A total of 32 Arctic grayling were marked downstream of the culvert site, of these, 25 (78%) were recovered upstream within 24 hours, four (13%) were recaptured between 25 and 48 hours while the remaining three (9%) were recovered after 48 hours had elapsed. Maximum mean cross-sectional velocities encountered within the culvert at this time ranged from 0.14 $m \cdot s^{-1}$ at the culvert inlet to 0.07 $m \cdot s^{-1}$ at the outlet with a discharge rate of 0.18 $m^3 \cdot s^{-1}$.

Tag recovery from previous study years included a single four year old Arctic grayling, originally tagged at Creek Mile 59.3 on May 20, 1979 and subsequently recovered at Creek Mile 51.9 on May 13, 1980 (Table 6). During that time interval this individual gained 33 mm in fork length and 45 g in weight.

Longnose sucker in spawning condition were captured from May 8 to May 17. In total, 27 longnose suckers are known to have migrated past the highway in 1980 with all but two fish in spawning condition. Mean fork lengths reported for spawning longnose sucker was 302 mm (SD=24.0) for 15 males, range = 262-334 mm; and was significantly higher at 351 mm (SD=22.7) for 10 females, range = 301-386 mm.

Recapture of marked longnose sucker upstream of the culvert indicated a 100% success rate in ability to pass through the culvert structure. Of sixteen marked fish, six (38%) were recaptured within 24 hours, four (25%) were recovered from 25 hours to 48 hours and two (13%) were recovered from 49 hours to 72 hours. The remaining four (25%) were captured upstream of the culvert after more than 72 hours had elapsed.

Gonadal development as assessed by expression of spawning products, indicated that all suckers were in a mature but not ripe state. As such spawning was not imminent and this may account for the relatively long transit times taken to pass through the culvert. Maximum mean cross-sectional velocities encountered in the culvert by spawning longnose sucker ranged from 0.06 $m \cdot s^{-1}$ at the culvert inlet to 0.03 $m \cdot s^{-1}$ at the outlet at a discharge rate of 0.13 $m^3 \cdot s^{-1}$.

Two northern pike in spawning condition were captured at the highway crossing on May 14. Fork lengths recorded for these fish were 450 mm and 454 mm. The scant number of northern pike observed compared to 1978 is likely attributable to low water conditions. Discharge rate as of May 14 was 0.09 $m^3 \cdot s^{-1}$ so that in culvert mean cross-sectional velocities can be expected to be very similar to those portrayed for May 13 in Fig. 19. In addition, juvenile Arctic grayling, longnose sucker, and slimy sculpin were also captured in fry traps during the latter part of the spring survey.

Both young-of-the-year and adult Arctic grayling were captured consistently during the summer and fall surveys. Young-of-the-year Arctic grayling grew about 24 mm in length between July 14 and September 18 (Table A10). The data also shows that little growth occurs for young-of-the-year over the winter period. A sample of six young-of-the-year fish collected on July 14 had a mean fork length of 48 mm (SD=4.7; range = 44-55 mm); and a sample of five fish collected September 18 had a mean fork length of 73 mm (SD=5.3; range = 66-79 mm). Comparatively, four yearling Arctic grayling captured May 20-21 had a mean fork length of 81 mm (SD=5.3; range = 76-88 mm). Fork lengths for large Arctic grayling

caught in gillnets over the summer/fall period ranged from 213-217 mm (n = 2) in July, 204-287 mm (n = 2) in August and 183-213 mm (n = 3) for September. Age class representation was from 2-5 years.

Three northern pike ranging from 220-375 mm in fork length were caught in gillnets during the September survey. Stomach analysis showed that two were empty while the other contained slimy sculpin.

Slimy sculpin, although initially caught sporadically during the May survey, were most abundant during the fall survey. On September 17-18 a total of 340 slimy sculpin were caught within a single fry trap. A sub-sample of these were retained for analysis of fork length, weight and age (Table A11). The large number of slimy sculpin, all of which were migrating downstream, suggests that emigration of this species was occurring at that time. Northern redbelly dace were also collected for the first time during the fall survey.

Stomach analysis of Arctic grayling indicated a highly diversified diet (Table 12). Stomach content analysis for slimy sculpin caught during the fall indicated that very light feeding was taking place. Smaller fish appeared to feed on aquatic invertebrates particularly Diptera; fish remains were found in larger fish (Table 13).

1981 study year

Stream discharge during the 1981 spring study ranged from 0.49 $m^3 \cdot s^{-1}$ on May 3 to recorded maximum of 10.09 $m^3 \cdot s^{-1}$ on May 6 (Fig. 2). Discharge declined steadily after peak conditions were reached. Maximum mean cross-sectional velocity measured at the culvert outlet was 2.66 $m \cdot s^{-1}$ at a discharge rate of 10.09 $m^3 \cdot s^{-1}$ on May 6 (Fig. 20). Mean cross-sectional velocities declined after peak flow reaching a minimum of 0.36 $m \cdot s^{-1}$ at 1.46 $m^3 \cdot s^{-1}$ on May 17. Corresponding velocity distributions for each transverse culvert section are presented in Fig. 21. Individual point velocity measurements are provided in Table A13. Substrate at all transects initially consisted of ice and ice rich silt materials; by May 10 a gravel/gravel-silt base was exposed.

Stream flow at maximum discharge was not entirely contained within the constructed channel, particularly upstream of the culvert where widespread flooding above the embankments occurred. Substantial erosion both above the embankments as well as within the channel occurred as a result.

Analysis of suspended solids levels from upstream and downstream sites was again undertaken in 1981 (Table 10). Although maximum levels of 0.123 $g \cdot L^{-1}$ from the upstream site and 0.243 $g \cdot L^{-1}$ from the downstream site were obtained during flood conditions on May 8, the maximum differential between the stations occurred on May 3 with 0.010 $g \cdot L^{-1}$ reported for the upstream site and 0.165 $g \cdot L^{-1}$ for the downstream site. Suspended solids levels measured after flood conditions indicated a seven fold increase between the upstream and downstream stations with 0.016 $g \cdot L^{-1}$ and 0.108 $g \cdot L^{-1}$ reported respectively. Channel slumping and associated erosion within the construction zone is thought to have been responsible for the elevated downstream levels.

Water temperatures measured over the spring study rose steadily from 0.5°C on May 5 to a recorded maximum of 10.0°C on May 19. The 1981 record of measured water temperatures together with calendar catch frequency for Arctic grayling, longnose sucker and northern pike is in Fig. 17.

Gillnets were set near the construction zone between May 10 and May 20. High flow and heavy debris severely limited the number of fish caught. In total, six longnose sucker and two northern pike in spawning condition were captured after May 18. Mean cross-sectional velocities in the culverts encountered by both longnose sucker and northern pike were 0.36-0.41 $m \cdot s^{-1}$ on May 17. At the culvert outlet 100% of cross-sectional area was flowing at $\leq .60$ $m \cdot s^{-1}$; at mid-culvert the value was 96.8% and at the inlet 87.3% (Fig. 21). Individual fish data for longnose sucker and northern pike are in Table A11.

A single longnose sucker tagged on May 10, 1980 was recovered on May 18, 1981 (Table 6). No increase in fork length and a loss in weight of 10 g was realized over the one year interval.

Spawning fish continued to be caught at the highway crossing as late as May 20, at the end of our survey, indicating that spawning migrations were not fully documented in 1981.

CREEK MILE 59.3

1978 study year

Stream discharge for the spring period ranged from a maximum of 0.64 $m^3 \cdot s^{-1}$ on May 7 to 0.09 $m^3 \cdot s^{-1}$ recorded on June 4 (Photo 13). The hydrograph for Creek Mile 59.3 is supplied in Fig. 2. Hydrologic data for Creek Mile 59.3 were collected in 1978 by the Arctic Hydrology Section of the Inland Waters Directorate (Grey, personal communication). As a result no velocity measurements or stream cross-sectional profiles are provided herein.

Water temperatures measured for the spring period rose steadily from 4.5°C on May 11 to a recorded maximum of 14.0°C on June 2. A calendar record of discharge and temperatures together with catch frequency data for Arctic grayling and longnose sucker is provided in Fig. 22.

During the spring period, migrating Arctic grayling and longnose sucker were captured moving upstream through a counting fence situated approximately 250 m upstream of the highway alignment or were caught in nearby gillnets.

Arctic grayling in spawning condition initially appeared in gillnets on May 15 and were consistantly caught until May 25 (Photo 14). However, the majority of fish captured after May 18 were spent. In total, 69 Arctic grayling

were captured by the fence and gillnet operation.

Mean fork length for 52 spawning Arctic grayling was 267 mm (SD=33.1) ranging from 209-332 mm. No significant difference (α= 0.05) was detected in mean fork length between sexes.

Mean age for 27 spawning male Arctic grayling was 4.1 yr (SD=0.93; range = 3-6 yr) whereas for 23 females it was higher at 4.7 yr (SD= 0.83; range = 3-6 yr).

Longnose sucker in spawning condition were present from May 18 to June 5. Mean fork length for 38 spawning female longnose sucker was 331 mm (SD=30.8; range = 242-372 mm whereas for 29 males it was significantly lower (α = 0.05) at 302.4 mm (SD=22.7; range = 253-341 mm). In total, 69 longnose sucker moved upstream through the trap.

It is likely that at least Arctic grayling spawning occurred in this area immediately upstream of the counting fence. Tagged Arctic grayling were observed to remain in this area throughout the spring study period and Arctic grayling fry were first detected in abundance here. Longnose sucker spawning must also occur upstream of the counting fence.

Incidental fish species caught during the spring period included two immature white sucker and a single spent northern pike.

Arctic grayling fry were first detected in Creek Mile 59.3 on June 5 and were observed daily until the end of the spring survey on June 8. The fry were observed in shallow areas along the stream edge. Mean fork length for 117 Arctic grayling fry collected June 5-8 was 14 mm (SD=1.1; range = 11-17 mm).

Physical data collected during the fall survey, September 20-24 included measured water temperatures of 5.5-6.5°C and stream discharge of 0.03 $m^3 \cdot s^{-1}$.

Gillnets set during the fall survey yielded both immature and mature grayling. Fork length for 10 large fish ranged from 120-314 mm with ages from 1-4 yr. Included among these was a tag recovery from the spring program (Table 6). This four-year old individual recaptured on September 22 had a net gain of 15 mm fork length over 93 days.

Also collected in fry traps during the fall survey were young-of-the-year and one-year old grayling as well as longnose sucker ranging in age from young-of-the-year to age 3. Mean fork length for 34 young-of-the-year Arctic grayling at this time was 56 mm (SD=10.4; range = 38-84 mm). Mean fork length for seven age 1 Arctic grayling (includes samples from previously mentioned gillnet catches) was 130 mm (SD= 7.1; range = 120-140 mm). A growth in length summary for Arctic grayling by age class and sample period is included in Table A14.

Mean fork length calculated for 37 young-of-the-year longnose sucker captured on September 21-22 was 41 mm (SD=5.2; range = 29-53 mm). Difficulty in age interpretation beyond the young-of-the-year class prevent further analysis of these fish, however, some tentative ages are included in Table A15 along with individual data for all fish caught.

Detailed stomach content analysis for Arctic grayling by fork length class and sample period is provided in Table 14. In general, fish of fork length under 100 mm appear to have a preference for Diptera, Plecoptera and Trichoptera larvae in order of abundance, whereas Trichoptera larvae were the dominant item found in fish stomachs of the larger classes.

1979 study year

On April 5, 1979 excavation for culvert installation was in progress at Creek Mile 59.3. A small amount of flowing water was evident near the excavation site as a result of ground water recharge. Instream icing was widespread. Water quality measurements were made in a beaver pond located approximately 300 m upstream of the alignment. A dissolved oxygen concentration of 1.5 $mg \cdot L^{-1}$ and conductivity of 300 µmhos at 0.5°C were measured at this time. A strong odour of hydrogen sulphide was present indicating anaerobic conditions and precluding the presence of overwintering fish.

As of May 1, installation of a 4.3 m S.P.C.S.P. culvert was complete (Photo 15). Riprapping and cleanup procedures were started in July and were generally complete by September. Technical data and the site plans for the culvert installation as provided by PWC are provided in Fig. 23.

Stream discharge measured during the spring period ranged from 0.42 $m^3 \cdot s^{-1}$ on May 10 to 3.38 $m^3 \cdot s^{-1}$ on May 20. Discharge declined steadily after the latter date until May 27 when a second smaller peak of 1.93 $m^3 \cdot s^{-1}$ occurred due to rainfall (Fig. 2).

The maximum mean cross-sectional velocity within the culvert was 1.35 $m \cdot s^{-1}$ measured at the culvert outlet on May 20 at a discharge rate of 3.38 $m^3 \cdot s^{-1}$. Mean cross-sectional velocities were much lower at a given discharge rate after peak flows as compared to the same discharge rate prior to the peak. This is attributed to the scouring and ice removal by high flows resulting in an increase in bed roughness.

Large deposits of debris and excavated material were situated adjacent to the stream channel during the spring period. High suspended solids levels and increased debris were in the channel as a result of rainfall and increased flow conditions. A comparison of suspended solids concentrations measured at upstream and downstream locations is provided in Table 10. The maximum suspended solids concentration of 0.247 $g \cdot L^{-1}$ occurred during peak flow conditions on May 19. The maximum differential in suspended solids concentrations between upstream and downstream stations occurred immediately prior to and after peak flows. Higher suspended solids concentrations were consistently reported from the downstream station. This condition was also in evidence during the July and August surveys whereas the September survey indicated approximately equal values from both

sites. Discharge measured on September 8 was 0.08 $m^3 \cdot s^{-1}$.

Maximum daily temperature increased slowly from 0°C last reported on May 8 to 12.5°C on May 25. Water temperature fluctuated considerably (Fig. 22).

Arctic grayling in spawning condition were first found in the fish fences on May 17. High water conditions which began on May 18 eventually led to the use of gillnets for the collection of fish data. Arctic grayling regularly appeared in gillnets until May 25. Mean fork length for 24 spawning Arctic grayling was 271 mm (SD=34.9; range = 197-325 mm). Corresponding mean age for these fish was 4.3 yr (SD=0.86; range = 3-6 yr). No significant difference (α=.05) in fork length or age between sexes was found. The few Arctic grayling caught after May 25 were not in spawning condition.

Longnose sucker were initially captured on May 24 and dominated the catch to the termination of the survey on June 4. In total 83 longnose sucker were captured, all of which were in spawning condition. Mean fork length reported for 41 males was 300 mm (SD=19.3; range = 247-342 mm) whereas for 35 females mean fork length was significantly higher (α=.05) at 330 mm (SD=32.5; range = 265-389 mm). Spent longnose sucker were not encountered at any time during the spring survey.

Young-of-the-year Arctic grayling were captured during each of the summer and fall sample periods. Information collected from gillnet sets indicate that both immature and mature grayling reside in the stream during the summer. Two and three year old Arctic grayling ranging from 171-261 mm in fork length were caught during the July survey. Arctic grayling from one to four years old ranging from 157-288 mm in fork length were captured during the August survey while one fish aged five years with fork length of 302 mm was taken during September (Table A14). Additional information on annual growth was provided by tag recoveries (Table 6). Two Arctic grayling originally tagged in 1978 were recaptured during the spring survey in 1979. One of these, a male, tagged on May 5, 1978 at age 5 and recaptured on May 21, 1979 gained 13 mm fork length and 50 g in weight over the period. Detailed stomach analysis for Arctic grayling is in Table 15.

A single young-of-the-year longnose sucker measuring 38 mm in fork length was collected at the highway alignment during the August survey.

Individual fish data for all species caught are in Table A15.

1980 study year

Icing throughout the culvert and surrounding area was pronounced during the spring of 1980. Ice accumulations were often in excess of two meters in depth. Low spring flow conditions were unable to dislodge the ice mass from within the culvert and as such the ice remained throughout the spring period.

Maximum flow encountered during the spring period was 0.11 $m^3 \cdot s^{-1}$ on May 1. Flow rate declined slowly thereafter reaching a minimum of 0.07 $m^3 \cdot s^{-1}$ on May 13 (Fig. 2). Stream flow within the culvert occurred primarily beneath the ice layer and between the riprap material with some channelization along the culvert wall (Photo 16). The presence of ice prevented in-culvert measurements prior to May 13. After this date and until July, measurements were made only at the culvert outlet. Point velocity measurements at the culvert outlet are provided in Table A16. Typical culvert cross-sectional profiles for Creek Mile 59.3 collected over the spring and summer periods are presented in Fig. 24. Mean cross-sectional velocities at the culvert outlet during the spring were 0.13 $m \cdot s^{-1}$ and 0.19 $m \cdot s^{-1}$ at discharge rates of 0.07 $m^3 \cdot s^{-1}$ and 0.08 $m^3 \cdot s^{-1}$ respectively.

Water temperatures measured during the spring program ranged from a minimum of 5.0°C on May 3 to a maximum of 15.0°C on May 15 (Fig. 22). Water temperatures measured during the spring period were consistently higher at Creek Mile 59.3 than at the other streams under study.

Surface erosion occurred again along adjacent roadside slopes, but was not as pronounced as at other locations studied. Suspended solids concentrations recorded from upstream and downstream sites over the course of the study year are presented in Table 16. Downstream sites registered 1.3-26.0 times the suspended solids concentration as did upstream sites; thereafter an approximate 3.5 fold increase was maintained.

Spawning Arctic grayling were first captured (Photo 17, 18) at the highway on May 6 and continued to appear as late as May 13; after this date only spent and immature grayling were observed (Fig. 22). However, the flow appeared to be turbulent. In total 74 Arctic grayling migrated past the highway crossing with 40 of these positively identified as spawners. Mean fork length for the 40 spawning Arctic grayling was 249 mm (SD=39.4; range = 177-334 mm). No significant difference (α=0.05) in mean fork length between sexes was found. Overall mean fork length for 70 Arctic grayling migrants was 241 mm (SD=41.9; range = 162-334 mm).

Mean age of 41 spawning Arctic grayling was 4.1 yr (SD=1.0; range = 3-7 yr). Again, no significant difference (α=0.05) was found in mean age between sexes.

Tag recaptures from previous years of study consisted of two fish originally tagged in 1978. One of the fish had previously been recovered in the 1979 study. Data collected from these fish is presented in Table 6. The 1980 tagging program included marking a total of seven Arctic grayling in order to document their passage through the culvert. Six Arctic grayling (86%) were recovered upstream of the culvert within 24 hours with the remaining fish captured in under 48 hours.

Two longnose sucker, with only one in spawning condition, were captured at the highway crossing over the spring period. This number is

substantially lower than reported for 1978 and 1979 when 69 and 83 longnose sucker were caught respectively.

Discharge measured during the summer and fall surveys fluctuated with amount of precipitation experienced. Rainfall resulted in discharge of 0.19 $m^3 \cdot s^{-1}$ on July 13 whereas a relatively dry spell prior to the August survey reduced discharge to a recorded low of 0.01 $m^3 \cdot s^{-1}$ on August 18. Discharge was again restored to 0.09 $m^3 \cdot s^{-1}$ on September 17 (Photo 19). Water temperatures included 14.0-13.0°C for July 13-14, 12.5°C for August 17, and 7.0°C on September 16. Rainfall during the September survey produced an increase in suspended solids levels of approximately 40 times between upstream and downstream locations.

Resident fish caught in gillnets during the summer and fall surveys included nine Arctic grayling ranging in fork length from 173-237 mm and a single longnose sucker (152 mm) caught in September. Arctic grayling caught ranged in age from 2-4 yr with age 3 being dominant numerically. In addition, young-of-the-year Arctic grayling were caught during each of the summer and fall surveys.

Growth in length data for all Arctic grayling caught in 1980 is provided by sample period in Table A14. Little growth occurred for young-of-the-year Arctic grayling after August. Individual fish data are in Table A15.

Diptera larvae were by far the most abundant item found in those Arctic grayling with fork length less than 100 mm (Table 17). These fish were represented exclusively by young-of-the-year Arctic grayling in 1980. Larger fish appeared to feed upon a broader base with Trichoptera larvae, Coleoptera and Hemiptera among the dominant groups.

1981 study year

Collection of physical data was started on May 3 during the 1981 study. Icing, created by ground water recharge and associated overflow, was again a prominent feature at this stream. Accumulations in excess of 1.5 m were found within the culvert and throughout the stream (Photo 20). Icing was more pronounced upstream of the culvert than at downstream locations. High water flows encountered in 1981 were effective at rapidly incising a channel through the ice layer reaching the substrate on May 7 (Photo 21), and completely freeing the culvert of ice by May 8.

Stream discharge increased rapidly from 0.63 $m^3 \cdot s^{-1}$ on May 3 to a recorded maximum of 3.57 $m^3 \cdot s^{-1}$ on May 7, then declined steadily (Fig. 2). Mean cross-sectional velocities and water velocity profiles at measured discharges for each of the transect sites are in Fig. 25. The corresponding velocity distributions for each station are presented in Fig. 26. Individual point velocity measurements are in Table A17. Mean cross-sectional velocities measured over the ice surface ranged from 1.23 $m \cdot s^{-1}$ at a discharge rate of 0.86 $m^3 \cdot s^{-1}$ on May 4 to a maximum of 3.47 $m \cdot s^{-1}$ on May 6 at a discharge of 2.34 $m^3 \cdot s^{-1}$. Maximum mean cross-sectional velocities measured over the culvert substrate ranged from 0.90 $m \cdot s^{-1}$ at 1.51 $m^3 \cdot s^{-1}$ for the culvert inlet on May 11, to 0.60 $m \cdot s^{-1}$ at 0.66 $m^3 \cdot s^{-1}$ on May 19 for the outlet. Mean cross-sectional velocities were consistently lowest at the middle station.

Substrate in the culvert consisted of boulders with course interstitial gravels. Conditions remained relatively constant although some scouring of loose gravels occurred exposing the culvert plates (Photo 22).

Suspended solids concentrations were again monitored from upstream and downstream sites in 1981. Maximum levels of total suspended solids were reported from both stations during high flows on May 8, however, the greatest relative differential between stations occurred on May 4 with an approximate eight fold increase in total suspended solids indicated (Table 16). Suspended solids levels measured at the conclusion of the survey were 0.013 $g \cdot L^{-1}$ and 0.024 $g \cdot L^{-1}$ for upstream and downstream sites respectively representing an approximate two fold increase between stations. Erosion in the vicinity of Creek Mile 59.3 was not highly visible in 1981, again due in part to runoff occurring over frozen materials.

Between May 8 and May 20 a single fish fence was set downstream of the culvert and gillnets set in suitable upstream locations. Spawning Arctic grayling were first captured at the highway crossing on May 16 and continued to appear until May 20. On May 14 mean cross-sectional velocities in the culvert varied from 0.55 $m \cdot s^{-1}$ at midculvert to 0.63 $m \cdot s^{-1}$ at the inlet and 0.72 $m \cdot s^{-1}$ at the outlet. The percentage of cross-sectional area flowing at $\leq$0.60 $m \cdot s^{-1}$ varied from 55% at the inlet to 67% at midculvert to 32.5% at the outlet.

Mean fork length of 14 spawning female Arctic grayling was 246 mm (SD=23.8; range = 218-298 mm) whereas mean fork length of 27 spawning males was 229 mm (SD=19.2; range = 186-265 mm). The means are significantly different at $\alpha = 0.05$. Similarly, mean age of 12 spawning female Arctic grayling was 4.3 years (SD=0.5; range = 4-5 yr) while mean age of twenty-two males was significantly lower (α=.05) at 3.8 yr (SD=0.4; range = 3-4 yr).

A single Arctic grayling tagged on May 8 of the previous study year at age 4 was captured on May 16 and showed a gain of 7 mm in fork length and a loss of 11 g in weight over the period (Table 6). This Arctic grayling was emaciated at the time of capture.

Longnose sucker first appeared at the highway crossing on May 19. A sample of 13 longnose suckers was collected on May 19 and May 20, after which the survey was terminated. Mean fork length of these fish was 320 mm (SD=26.9; range = 280-364 mm). Small sample size prevents male/female comparison.

Two tagged longnose sucker from previous study years were captured. See Table 6 for comparative growth data. Individual data on all fish captured in 1981 are included in Table A15.

DISCUSSION

CREEK MILE 48.9

Over the four years of study, Creek Mile 48.9 at the highway crossing was subjected to a range of flow conditions varying from a low maximum discharge rate of 0.11 $m^3 \cdot s^{-1}$ in 1980 to a high maximum measured discharge rate of 2.38 $m^3 \cdot s^{-1}$ in 1981. The latter flow rate is still far below the calculated fish migration discharge (recurrence interval 1:2.33 yr) of 7.93 $m^3 \cdot s^{-1}$ used for culvert design purposes.

Construction of the culvert crossing began prior to the spring freshet of 1979. However, the installation was not completed at that time. No evidence of rock placement in the culvert (as per design specifications) was found except near the culvert inlet where rock had been placed on top of approximately 2 m of silt. As a result hydraulic measurements taken in 1979 were not representative of the culvert operating under stream simulation conditions. Final site grading and embankment stabilization were also not included in the original construction activity. Further remedial work was begun in the late summer of 1979 and continued into the winter of 1980. At this time additional riprap material was placed in the culvert and stream channel and an attempt was made to stabilize the foreslopes and ditches.

Severe erosion occurred again in the spring of 1980 and as a result much of the rock material which was in place at the time of our study in 1980 was overlain by silt deposits up to 1 m in depth. It was impossible therefore to determine whether the rock was placed as the design called for. Flow conditions in 1980 were insufficient to remove silt material from the culvert to expose the underlying riprap. Erosion continued largely unabated throughout the ensuing summer.

Flow conditions in 1981 were much higher and were able to remove much overlaying material from the culvert. Even though erosion continued at an alarming rate from the foreslopes the hydraulic measurements taken in 1981 are more indicative of velocities occurring as a result of placement of rock riprap on the culvert floor.

Hydraulic conditions present did not appear to hinder fish migration in any year of study although only a few Arctic grayling and longnose sucker actually attempted to migrate upstream through the area. In the natural channel studied in 1978 mean cross-sectional velocity was 0.37 $m \cdot s^{-1}$ at a discharge rate of 0.51 $m^3 \cdot s^{-1}$. Comparatively, the mean cross-sectional velocity in the culvert operating under stream simulation conditions was 0.25-0.33 $m \cdot s^{-1}$ at a discharge rate of 0.75 $m^3 \cdot s^{-1}$ in 1981.

Given the minimum fork lengths by species for ripe individuals captured in Creek Mile 48.9 and utilizing swimming performance data provided in Jones et al. 1974, (Table 18) it is possible to calculate the critical culvert velocity which would allow all individuals of greater or equal fork length to migrate successfully through the culvert. For purposes of this discussion we will consider the maximum velocity that can be maintained by a fish for 10 minutes to be the critical swimming velocity. This velocity is fork length and species dependent. However, this approach may not be valid for culverts constructed for stream simulation since the basic premise of this construction technique is that fish do not have to traverse the culvert in a single continuous effort. As a result fish are able to utilize their much higher but less sustainable burst speeds through areas of high velocity combined with rest in areas of very low velocity. If this situation is in fact achieved in the culvert it can be expected that the values calculated in the following paragraphs are conservative in nature (i.e. smaller individuals than those indicated could migrate through the structure).

In the case of Creek Mile 48.9, since the culvert is 47.3 m in length, any fish must attain a ground speed greater than or equal to 0.08 $m \cdot s^{-1}$ in order to traverse the distance in ten minutes or less. The shortest Arctic grayling in spawning condition captured in Creek Mile 48.9 had a fork length of 190 mm. The critical swimming velocity calculated from Jones et al. 1974 for such an individual is 0.63 $m \cdot s^{-1}$. Therefore a water velocity of 0.55 $m \cdot s^{-1}$ (critical culvert velocity) in the culvert should allow passage of this individual as well as any other with a greater fork length. Similarly the value for longnose sucker in the stream is 0.71 $m \cdot s^{-1}$ based on a fork length of 328 mm. As a result the lesser value (i.e. 0.5 $m \cdot s^{-1}$) should allow passage of all spawners encountered of both species.

This method assumes that velocities less than or equal to the value can be found throughout the culvert and fish can find them and continuously orient themselves to swim through these areas. Examination of mean cross-sectional velocity profiles for the culvert installation would seem to indicate that at least the first assumption is true. The culvert at a discharge of 0.75 $m^3 \cdot s^{-1}$ on May 14, 1981, had a minimum of 95.8% of cross-sectional area comprised of velocities less than or equal to 0.60 $m \cdot s^{-1}$. Even at the much higher discharge rate of 1.85 $m^3 \cdot s^{-1}$ on May 8, 1981, well before fish attempted to migrate through the structure, at least 25.4% of cross-sectional area was comprised of velocities less than or equal to 0.60 $m \cdot s^{-1}$. In the natural channel in 1978 mean cross-sectional velocity was 0.37 $m \cdot s^{-1}$ and 87% of flow area had velocities $\leq$0.60 $m \cdot s^{-1}$ at a discharge rate of 0.51 $m^3 \cdot s^{-1}$. We consider that the culvert installation in Creek Mile 48.9 compares favourably to the natural channel and presents no barrier to spawning migrations of important fish species at the stream flow rates measured.

As a result of a survey completed in 1977 (McKinnon and Hnytka 1979) the stream system encompassing Creek Mile 48.9 and Creek Mile 49.9 was considered to provide favourable habitat for at least six species of fish including Arctic grayling. Sampling effort indicated that the Arctic grayling spawned in Creek Mile 48.9 possibly at locations upstream of the proposed highway crossing. Fish passage facilities were considered necessary to accommodate spring spawning fish at this location.

Results of the sampling efforts over the four years of this study do not substantiate these earlier indications. Although discharge levels varied considerably over the course of study they did not approach the mean annual flood estimated by hydrologic analysis at any time. Since beaver dams occur frequently along the course of Creek Mile 48.9 it is possible that under very low flows these act as barriers to the upstream migration of significant numbers of fish. Based on our study, Creek Mile 48.9 at the highway crossing does not provide a migration route for significant numbers of important fish species (as defined by Dryden and Stein 1975). The area does provide some minor amount of spawning habitat for both Arctic grayling and longnose sucker but more significantly it provides feeding habitat for juveniles of both species. The area also provides spawning habitat in most years for brook stickleback and finescale dace.

One noteworthy point is that one Arctic grayling tagged in Creek Mile 51.9 in 1980 was recaptured in Creek Mile 48.9 in 1981. This indicates that some interchange of Arctic grayling occurs between neighbouring tributaries of the Liard River.

CREEK MILE 50.7

Large variations in stream discharge during the spring were recorded over the course of the study. Peak discharge was 1.00 $m^3 \cdot s^{-1}$ in 1978, 6.80 $m^3 \cdot s^{-1}$ in 1979, 0.08 $m^3 \cdot s^{-1}$ in 1980 and 5.36 $m^3 \cdot s^{-1}$ in 1981. The estimated 1:50 year flow and mean annual flow (fish migration discharge) are 22.32 $m^3 \cdot s^{-1}$ and 11.33 $m^3 \cdot s^{-1}$ respectively.

The culvert construction timetable for Creek Mile 50.7 was very similar to that of Creek Mile 48.9. Culvert placement was undertaken prior to the freshet in 1979, however, slope stabilization, culvert riprap and ditch checks were not put in place at this time. Remedial measures were as described for Creek Mile 48.9. Erosion in the vicinity of the highway was severe in both 1979 and 1980. Ditch erosion produced gullies and moved large amounts of fine material to the stream bed where it was subsequently deposited. Only in 1981 did the stream clear itself of silt sufficiently so that velocities in the culvert were affected by the placement of rock riprap. Prior to this time most in-culvert riprap was overlain with up to 1 m of silt.

Mean cross-sectional velocity in the natural channel in 1978 was 0.38 $m \cdot s^{-1}$ at a discharge of 1.00 $m^3 \cdot s^{-1}$. At this time 100% of flow area had velocities <0.5 $m \cdot s^{-1}$ and 72% was ≤ 0.40 $m \cdot s^{-1}$. Discharges in 1980 were extremely low and are not comparable, however, the maximum mean cross-sectional velocity recorded was 0.31 $m \cdot s^{-1}$ at a discharge of 0.08 $m^3 \cdot s^{-1}$. A comparative discharge of 0.74 $m^3 \cdot s^{-1}$ in 1981 produced a maximum mean cross-sectional velocity of 0.31 $m \cdot s^{-1}$. At this time 100% of flow area at the three sites measured had velocities <0.60 $m \cdot s^{-1}$ and a minimum value of 82.5% of flow area had velocities ≤ 0.40 $m \cdot s^{-1}$. Mean cross-sectional velocities were 1.61-1.95 $m \cdot s^{-1}$ over ice in the culvert in 1981, however, once flow became established over a boulder/gravel substrate in the culvert mean cross-sectional velocities were 0.33-0.49 $m \cdot s^{-1}$ at a discharge rate of 1.81 $m^3 \cdot s^{-1}$.

Using the approach outlined for Creek Mile 48.9 we calculate a critical culvert velocity of 0.55 $m \cdot s^{-1}$ for Arctic grayling and and 0.60 $m \cdot s^{-1}$ for longnose sucker in Creek Mile 50.7. These values are based on minimum fork lengths for spawning individuals of 163 mm and 302 mm for Arctic grayling and longnose sucker respectively. The culvert length in this instance is 42.7 m therefore the ground speed to be attained by any fish attempting to traverse the distance in ten minutes is 0.07 $m \cdot s^{-1}$. The culvert installation in 1981 had 100% of measured velocities ≤ 0.60 $m \cdot s^{-1}$ at a discharge of 0.74 $m^3 \cdot s^{-1}$ which corresponded to the first arrival of spawning migrants of both Arctic grayling and longnose sucker. At the same time a minimum of 82.5% of velocities were ≤ 0.40 $m \cdot s^{-1}$.

Creek Mile 50.7 and Creek Mile 51.9 follow parallel courses before converging into a common channel that discharges in the Liard River. The presence of both juvenile and mature fish and the diversity of species in 1977 indicated that Creek Mile 50.7 provided important spawning, nursery and feeding areas for fish. Both spring and fall spawning species were captured in the system and it was therefore considered essential that neither spring nor fall instream construction be allowed in addition to the fish passage requirement.

It was not possible to fully document the extent of spawning migrations past the highway crossing point in 1978 due to the use of gillnets as the capture method. However the presence of spawning fish was indicated. The vast majority of fish moving upstream at the highway crossing, however, were in spent condition and may indicate post-spawning feeding movement. The abundance of juvenile and immature Arctic grayling and longnose sucker indicate an important role as nursery and feeding habitat. The capture of white sucker, slimy sculpin, lake chub and brook stickleback provide additions to the 1977 fish species list for the stream.

The extent of spawning migrations past the highway crossing point was not determined in 1979. A gap in biological data collection occurred for the duration of peak flow . The migration of Arctic grayling began immediately prior to flood conditions and had tapered off once water levels receded while longnose sucker began their spawning migration during peak flow. The migration of both of these species during peak flow conditions appears to be an anomaly and was coincidental upon a sudden increase in stream flow due to precipitation. It seems probable that undetected movement of both Arctic grayling and longnose sucker occurred during peak flow conditions when biological sampling was not carried out.

Spawning Arctic grayling in Creek Mile 50.7 was documented in 1980. The spawning migrants reaching the highway were observed to consist mainly of very small individuals. This observation is not consistent with previous years' data. Data collection techniques in 1979

may have been biased towards larger fish, however this does not account for the absence of larger grayling in the 1980 sample.

Fecundity analysis was performed on four Arctic grayling under 200 mm fork length during the spring period. All were age 3. The mean number of ova per female was 912 (range: 649-1 433). Comparatively the mean number of ova per female for Providence Creek (Falk et al. 1982) was 11 229 (range = 4 694- 15 867; n = 10) for grayling (length range 373-432 mm). Ages for these latter fish were not determined.

Arctic grayling and longnose sucker passage through the culvert was observed to be unimpeded by conditions present in 1980 and 1981. The maximum mean cross-sectional water velocity encountered in the culvert during the period of Arctic grayling migration was measured at 0.15 $m \cdot s^{-1}$ on May 10 in 1980 and was 0.31 $m \cdot s^{-1}$ in 1981.

Longnose sucker migration was also unimpeded by the culvert in 1981.

Habitat utilization above the highway crossing by Arctic grayling, longnose sucker and other fish species varies considerably from year to year. Generally the area is utilized as a spawning, nursery and feeding area. Fry survival is thought to be high due to the lack of predator species. A total of eight species of fish have been identified as utilizing the stream in three years of study.

Uncontrolled erosion was observed to be a serious problem at Creek Mile 50.7 in 1979 and 1980. Short-term effects of silt addition are difficult to determine for streams such as Creek Mile 50.7 where seasonal and annual variation in biological parameters obscures possible impacts.

No evidence of fall spawning fish near the highway was found and it is considered that the imposed restriction on instream construction for the period September 1 to November 15 was unnecessary.

CREEK MILE 51.9

As was the case with other streams in the area, Creek Mile 51.9 was subjected to a variety of peak flow conditions over the course of the study. The minimum peak discharge level over the four years of study was 0.22 $m^3 \cdot s^{-1}$ in 1980 and the maximum peak level over the period was 10.09 $m^3 \cdot s^{-1}$ in 1981. These flows compare to an estimated 1:50 year design flow and mean annual flow (fish migration discharge) of 26.53 $m^3 \cdot s^{-1}$ and 13.68 $m^3 \cdot s^{-1}$ respectively.

Construction of the permanent culvert facility on Creek Mile 51.9 took a long time. At the commencement of the spring survey in 1979 installation of the proposed culvert had not begun. Instead, a diversion channel was excavated, diverting stream flow around the proposed culvert site. The stated purpose of this diversion was to allow the construction site to dry out. Also in operation at this time was a makeshift roadway which provided access across the diversion channel. A single 1.2 m culvert was installed beneath the roadway to allow water passage. Flood conditions commencing May 18 breached this temporary crossing. A temporary log bridge was built by May 22. Undercutting of the unprotected banks within the diversion channel, however, eventually led to the collapse of this structure on June 2. The construction and subsequent failure of these crossings, the stockpiling of fill material adjacent to the stream, diversion of stream flow into an unprotected channel and other construction related activities were all observed to affect water and substrate quality within the stream. Heavy concentrations of suspended solids and debris were evident within the stream throughout the construction zone and for a considerable distance downstream. Installation of the permanent culvert structure began in mid-July and was completed by August 19. Riprapping and cleanup were generally completed by September 8.

The construction practices evident in the construction of the culvert were not environmentally sound. The installation procedure was poorly planned and many of the activities near and in the stream were unnecessary. The contractor in this instance seemed to display a lack of concern for the aquatic environment.

Water samples taken above and below the construction zone revealed levels of suspended solids concentrations approximately three times higher in downstream locations as compared to upstream locations during high flows. When flood waters receded downstream values were as high as 19 times than those upstream. Maximum levels occurred concurrently for upstream and downstream locations at peak discharge. Water quality improvement occurred at a faster rate at upstream locations than was the case downstream.

Silt addition was observed to occur as a result of erosion within the construction zone from summer rainfall events. Even modest rainfall appeared to readily erode the exposed slopes without greatly altering the flow regime within the stream. As such the stream energy was insufficient to remove freshly acquired silts. Silt accumulations were pronounced in areas downstream of construction activities with heavy deposits remaining through to the fall.

Silt deposits were present throughout the lower reaches of Creek Mile 51.9 in 1979 and 1980 and to a much lesser extent in 1981. The 1980 spring freshet was incapable of removing the silt much of which was deposited in 1979. Some silt was added to the stream in 1980 by erosion along the highway right-of-way. The culvert installation did not approach stream simulation condition until much of the material was removed from the culvert by the freshet of 1981.

In the natural channel studied in 1978 mean cross-sectional velocity was 0.31 $m \cdot s^{-1}$ and 100% of flow area had velocities of ≤ 0.60 $m \cdot s^{-1}$ at a discharge rate of 1.55 $m^3 \cdot s^{-1}$. The culvert operating under stream simulation conditions in 1981 compared very favourably. At the three sites measured in the culvert at a discharge of 1.46 $m^3 \cdot s^{-1}$, the percentage of flow area ≤ 0.06 $m \cdot s^{-1}$ ranged from 87.3-100%.

The culvert installation in Creek Mile 51.9 is longer than that for either Creek Mile 48.9 or Creek Mile 50.7. Consequently the ground speed required by any migrant in the culvert is 0.10 $m \cdot s^{-1}$ if the fish utilizes the ten minute maximum swimming speed. Given the fork lengths encountered, the following are the critical culvert velocities by species; Arctic grayling 0.54 $m \cdot s^{-1}$, longnose sucker 0.51 $m \cdot s^{-1}$, northern pike 0.23 $m \cdot s^{-1}$ and white sucker 0.61 $m \cdot s^{-1}$. On May 17, 1981, there was a minimum of 87.3% of the cross-sectional area with velocities less than or equal to 0.60 $m \cdot s^{-1}$ and a minimum of 48.6% of area with velocities less than or equal to 0.40 $m \cdot s^{-1}$.

The conclusions drawn about Creek Mile 51.9 as a result of McKinnon and Hnytka (1979) were the same as those for Creek Mile 50.7 and as a result have been previously discussed.

No spawning areas were located in 1978 but these evidently exist in areas upstream of the highway. A relatively large number of longnose sucker migrated in 1978; much larger than in subsequent years. The presence of juvenile and immature fish indicates a role as nursery and feeding habitat.

The documentation of migration of spawning fish was not complete in 1979. Fish numbers taken in 1979 were reduced considerably compared to the 1978 data. Instream deposits of sediment were observed in downstream areas. The effect of these deposits on the overall productivity of the stream as well as both the direct and indirect consequences on the fish population are unknown.

Arctic grayling, longnose sucker and northern pike spawned upstream of the highway crossing in 1980. Numbers of pike and longnose sucker detected ascending the stream past the highway crossing were down markedly from 1978 which was the only other year in which a complete census of spawning migration was accomplished. The number of Arctic grayling in 1980 was much greater than in 1978. As was the case in Creek Mile 50.7, small Arctic grayling provided an important component in the total spawning migration. Recovery of a single Arctic grayling previously tagged at Creek Mile 59.3 indicates that there is some overlap of spawning habitat between these streams.

As with Creek Mile 50.7 no evidence of fall spawning fish was detected near the highway and as such the imposed construction restriction on fall instream construction was unnecessary. The capture of slimy sculpin and northern redbelly dace add to the 1977 species list.

CREEK MILE 59.3

Flow conditions varied from a low maximum discharge of 0.11 $m^3 \cdot s^{-1}$ in 1980 to a high maximum discharge of 3.38 $m^3 \cdot s^{-1}$ in 1979. The estimated 1:50 yr design flow for the installation is 13.54 $m^3 \cdot s^{-1}$ and the calculated mean annual flood is 6.51 $m^3 \cdot s^{-1}$.

On April 5, 1979, excavation was in progress and the permanent culvert was installed by May 1, 1979. All riprapping and erosion control measures were not completed at the time. Large quantities of debris and excavated material washed into the stream during and after the spring freshet. Final riprapping and cleanup began in mid-July and was completed by September. Some ditch erosion and slumping of the foreslope into the stream occurred adjacent to Creek Mile 59.3 but was not as pronounced as at other locations studied.

Suspended solids concentrations downstream of the culvert were generally two to three times those upstream during the spring period. However, by September there was little difference in water quality between upstream and downstream areas except following one rainfall event which produced a 40 fold difference in suspended solids levels between stations.

In 1980 icing within the culvert and throughout the construction zone was severe. Ice accumulated to depths in excess of two metres and extended throughout the culvert to a point approximately 80 m upstream. Ice was still present within the culvert at the termination of the spring survey on May 23. Elsewhere in the stream small amounts of ice were present in isolated patches. During the spring freshet and throughout the spring survey period in-culvert flow occurred primarily beneath the ice layer. The ice layer then became suspended by riprap material in the culvert. Some channelization of flow occurred along the culvert wall.

In addition to permitting passage of water beneath the suspended ice in the culvert at Creek Mile 59.3, riprap material was also effective in creating turbulent flow. Flow conditions within the culvert alternated between areas of nearly stationary water to chutes of high velocity flow and appeared to closely approximate flow in the natural stream.

Although icing was also present in the culvert at the onset of the spring freshet in 1981, flows were much higher than during 1980 and were effective in rapidly incising a channel through the ice layer to the substrate in the culvert.

Hydraulic measurements in the natural channel at the highway crossing of Creek Mile 59.3 were not taken in 1978 and as a result no direct comparison of the culvert installation to the natural channel is possible. However, the culvert appeared to simulate natural stream conditions. In 1981 mean cross-sectional velocity was 0.68-0.90 $m \cdot s^{-1}$ at a discharge rate of 1.51 $m^3 \cdot s^{-1}$.

The culvert installation on Creek Mile 59.3, at 58.5 m in length, is the longest of the four culverts under study. Three species of fish were found attempting to migrate through the culvert for the purposes of spawning. The critical culvert velocity for each of these species based on the minimum fork length encountered is 0.53 $m \cdot s^{-1}$ for Arctic grayling, 0.50 $m \cdot s^{-1}$ for longnose sucker, and 0.24 $m \cdot s^{-1}$ for northern pike. Arctic grayling initially appeared on May 16, and longnose sucker on May 19, 1981. On May 14 at a discharge rate of 1.08 $m^3 \cdot s^{-1}$ a minimum of approximately 32.5% of the

cross-sectional area of the flow in the culvert was flowing at a velocity less than or equal to 0.60 $m \cdot s^{-1}$. On May 19 at 0.66 $m^3 \cdot s^{-1}$ this value was approximately 60%. While this data is included for comparison, it is probable that fish would be able to use a combination of burst swimming and rest to traverse the culvert.

On the basis of data collection both in 1978 and 1979, it appears that Arctic grayling utilize an area immediately upstream of the highway crossing for spawning and rearing. Longnose suckers utilize areas further upstream of the culvert installation for spawning and rearing purposes. Longnose sucker were captured moving upstream in a ripe condition but subsequent sampling did not reveal either fry nor adults of this species near the alignment. In 1978, emigration of juvenile longnose sucker was noted at the highway crossing in late September.

It was not possible to fully document fish movement through the culvert in 1979, however, consistent observation of fish upstream of the culvert even during high flows seems to indicate that fish passage was not delayed by the installation.

A spawning migration of Arctic grayling was again seen at the highway crossing of Creek Mile 59.3 in 1980. Spawning migration of longnose sucker which were present in both 1978 and 1979 did not occur past the highway crossing in 1980. Fish passage was observed to be unimpeded by the culvert in 1980. In-culvert riprap created turbulent flow conditions within the culvert and culvert icing presented no problems to migrating fish. The latter situation was due to the presence of riprap within the culvert, without which fish obstruction may well have occurred.

Spawning migrations of both Arctic grayling and longnose sucker were documented migrating through the culvert structure in 1981 and no delays were noted.

The area of Creek Mile 59.3 above the highway provided spawning nursery and feeding areas for Arctic grayling and longnose sucker. Other species captured include white sucker and northern pike.

Mitigative measures in place for the highway crossing as proposed in McKinnon and Hnytka (1979) seem appropriate for the stream.

CONCLUSIONS

1. Consideration should be given to aligning highways as distant from a mainstream river as is practically possible. In the case of the Liard Highway, the alignment could have been constructed further inland in many areas. As a result fewer watercourses would have been crossed and therefore the number and cost of fish passage facilities would have been reduced. Additionally, the necessity of constructing the highway on Liard River alluvium deposits would have been avoided. The presence of these deposits at crossings was a major factor in producing erosion.

2. The major drawbacks of the design approach used to calculate flows for the Liard Highway streams were the lack of data and the simple method of expressing flow only as a function of drainage area. Any design approach should rely on data available and should take into account the relationship between flows and significant physiographical and climatological parameters. There are differences between some areas crossed by this highway and the Mackenzie Valley for which the design method was developed. An approach such as was put forward by Dillon Limited (1979) incorporating physiographical and climatological may have some merit.

3. Flows measured over four years of study on four streams did not approach the estimated average annual flood during any spring freshet.

4. Flow rates in all streams varied widely from year to year.

5. Culvert structures in streams should be constructed over a single time frame. This should include stream bank stabilization and, in the case of stream simulation, riprap placement on the culvert floor. The latter is especially difficult to accomplish during periods of stream flow. Diversion channels such as were constructed in Creek Mile 51.9 added large amounts of sediment to flowing water. For this reason culvert placement for stream simulation (i.e. complete with internal riprap) should be done during winter.

6. Some highway contractors displayed a lack of environmental awareness and disregard for the aquatic environment. The tendering process whereby highway construction contracts are awarded should take into consideration the past performance of any contractor in regards to environmental sensitivity.

7. Erosion was by far the biggest problem apparent during and after construction of the road grade. Attempts at controlling ditch erosion by means of ditchchecks were often meagre and initiated too late to be of value. Revegetation work was not completed until five years after construction; instead it should be an integral part of the main construction activity.

8. Uncontrolled chronic erosion along the roadway led to high suspended sediment levels in the streams under study and produced accumulations of sediment on the stream substrate. Habitat impairment and ultimately depletion of fish stocks are the likely outcome of chronic silt addition. Large additions of silt material to the stream when spawn is <u>in situ</u> can seriously impede egg survival.

9. Spawning migrations of fish were generally first noted after peak flow at the highway alignment. The exception was a result of a peak flow caused by rainfall. The timing of fish migrations as related to the stream hydrograph is undoubtedly a function of the distance of the sampling site from the mainstem Liard River. Also obstacles hindering migration cause delay. Many factors need to be taken into account on an individual stream basis in order to estimate fish arrival at a given site.

10. The timing of fish migrations in relation to peak flow is important because mean cross-sectional velocities at any given discharge rate are lower after spring freshet than before. This results from an increase in bed roughness due primarily to a reduction of ice content in the culvert. Fish migrating prior to the peak must contend with higher water velocities at any given discharge than would those migrating after peak.

11. Each stream under study displayed a high year-to-year variability of numbers and, to a lesser extent, species of fish migrating. The causative factors involved are not entirely clear however, there is a an inverse relationship to flow rate.

12. Some inter-tributary movement of Arctic grayling occurs along the Liard River. This fact tends to lessen the overall importance of any one tributary in providing habitat for Arctic grayling which spend part of their lives in the mainstem Liard River.

13. No spawning migration delays were apparent as a consequence of culvert installation.

14. Tagging data indicate that after spawning most Arctic grayling remain all summer in the headwaters of the streams in which they spawn.

15. Minimum fork lengths of spawning Arctic grayling in the streams under study are lower than reported elsewhere. Since fork length is an important determinate of swimming ability, it is vital to obtain this type of information for any fish-bearing stream in which a culvert is to be constructed.

16. The most significant spring migration species in the streams under study are Arctic grayling, longnose sucker and northern pike. The latter species occurs mainly in Creek Mile 51.9.

17. Culverts appeared to have areas of sufficiently low velocity to allow fish of the species and fork lengths encountered to successfully traverse the culverts utilizing 10 minute critical swimming velocity.

18. In Creek Mile 59.3 it appears that fish would be able to utilize burst speed coupled with rest periods to negotiate the culvert. This is the only culvert known to have rock riprap throughout its length.

19. Icing was a problem in some of the culverts under study. In our study it did not conflict with fish migration because of the time lapse involved, however, it could present a problem in some instances where culvert placement was closer to the tributary mouth.

20. The stream simulation approach to culvert design appears to be a valid concept. No migration delays could be attributed to the constructed culverts and velocities within the culverts were comparable to the natural stream.

21. The riprap material placed on the culvert floor appeared to be stable over the range of flows encountered. However, the stability of this material remains to be tested under more severe conditions.

22. An unexpected benefit of stream simulation became apparent in Creek Mile 59.3 in 1980. On this occasion flow became established under icing in the culvert and between the riprap material. Fish subsequently were able to migrate through the culvert under the ice layer. Had flow not become established on the culvert floor, a blockage to fish migration would almost certainly have occurred.

23. All four streams under study appear to provide excellent nursery and feeding habitat for Arctic grayling and longnose sucker. Food is abundant and predation is minimal except in Creek Mile 51.9 where northern pike are relatively abundant and as a result young-of-the-year and juvenile fish were relatively scarce. The latter contrasts to the adjoining Creek Mile 50.7 where the opposite situation occurs.

24. No overwintering areas were found in the streams under study and are not believed to exist. We surmise that fish emigrate to the Liard River for the winter period.

25. Three of the four streams under study provide spawning habitat for Arctic grayling and longnose sucker at or upstream of the highway crossing. As a result of the survey done in 1977 (McKinnon and Hnytka 1979) in advance of highway construction it was thought that all four streams provided some spawning habitat above the highway crossing sites.

26. The construction timing restriction, as recommended by McKinnon and Hnytka (1979) for Creek Mile 50.7 and Creek Mile 51.9 over the period September 1 to November 15 was unnecessary.

27. The numbers of fish captured in all streams under study are lower than was expected based on 1977 survey data.

28. Our data do not indicate that special considerations, beyond those already in place

for stream simulations, are required for culverts greater than 60 m in length.

RECOMMENDATIONS

1. More consideration should be given to environmental considerations in the initial alignment process. The Department of Fisheries and Oceans should be consulted at a early date.

2. The tendering process whereby highway construction contracts are awarded should take into consideration the past record of any contractor in regards to environmental sensitivity.

3. Erosion control and revegetation should be an integral part of the initial construction process (i.e. included in clearing, grading ... tender package.)

4. Culvert placement in streams which provide no overwintering habitat for fish should be during the winter period. The entire construction process including slope stabilization and provision for fish passage should be completed in one time frame.

5. Collection of physiographical, climatological and hydrological information should be done at an early stage. It is apparent that more hydrological instrumentation over a longer period of time is required in areas which can reasonably be expected to become sites for future linear developments.

6. The magnitude of flood events should be estimated on the basis of physiographic and climatological parameters not just drainage area. The concept developed by M.M. Dillon Limited (1979) should be re-evaluated as to its suitability for future use.

7. A survey of the fish resources should be carried out for any area where highway development is impending. The design of such studies requires further refinement and more intensive effort in order to collect all necessary biological information for proper culvert design. In addition to the information collected by McKinnon and Hnytka (1979), data are required for each stream on the timing of migrations relative to hydrological events, minimum fork length of spawning fish and location of spawning areas relative to the culvert site.

8. The stream simulation approach should be utilized in the future for fish passage in highway culverts. The definition of fish migration discharge in this regard may require revision from the present mean annual flood.

9. The Liard Highway culverts should be re-evaluated on a regular basis to determine the stability of riprap materials in the culverts.

10. The Department of Fisheries and Oceans document "Guidelines for the Protection of the Fish Resources of the Northwest Territories during Highway Construction and Operation" (Dryden and Stein 1975) should be revised to reflect current policy and state of knowledge. Recent studies including this one and Katopodis et al. (1978) have shaped the Departmental approach in this Region.

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Table 1. Meteorological data for Fort Simpson and Fort Liard, 1977-1981.[1]

Date	Mean Daily Temp. °C/Departure Normal		Total Prec.(mm)/Percent Normal	
	Fort Simpson	Fort Liard	Fort Simpson	Fort Liard
Oct/77	0.9/+0.6	+2.1/-	29.6/109%	1.0/-
Nov/77	-16.7/-1.4	-16.4/-	23.2/79	32.2/-
Dec/77	-30.0/-6.2	-27.2/-	8.7/38	43.5/-
Jan/78	-24.1/+3.5	-21.5/-	9.6/69	8.1/-
Feb/78	-15.0/+8.5	-11.9/-	5.3/37	9.2/-
Mar/78	-13.3/+0.5	-9.8/-	16.1/144	27.5/-
Apr/78	-3.0/-0.5	+0.6/-	14.2/93	7.0/-
May/78	+7.6/+0.5	+8.8/-	4.2/14	51.0/-
Oct-May	-11.9/+0.7	-9.4/-	110.3/73	179.4/-
Oct/78	-31.1/-1.6	+1.3/-	21.9/81%	12.1/-
Nov/78	-15.7/-0.4	-11.9/-	31.8/108	42.4/-
Dec/78	-23.3/+0.5	-22.4/-	15.9/69	17.2/-
Jan/79	-24.8/+2.8	-25.7/-	0.6/4	8.5/-
Feb/79	-31.5/-8.0	-28.0/-	8.9/63	9.5/-
Mar/79	-17.4/-3.6	-12.9/-	51.6/461	15.0/-
Apr/79	-5.8/-3.3	-1.3/-	8.8/58	22.5/-
May/79	+6.5/-0.6	+8.0/-	38.5/125	53.4/-
Oct-May	-14.4/-1.8	-11.6/-	178.0/121.1	180.6/-
Oct/79	+1.1/+2.6	+4.1/-	28.0/103%	3.0/-
Nov/79	-8.5/-6.8	-5.7/-	8.4/28	4.0/-
Dec/79	-20.4/+3.4	-16.8/-	12.7/55	16.0/-
Jan/80	-26.0/+1.6	-	22.6/161	-
Feb/80	-16.0/+7.5	-	10.3/73	-
Mar/80	-11.8/+2.0	-8.7/-	3.8/34	26.0/-
Apr/80	+4.1/+6.6	-	16.7/110	-
May/80	+10.4/+3.3	+12.0/	33.0/107	14.1/-
Oct-May	+4.2		135.8/3.8	
Oct/80	+2.3/+3.8		14.2/52%	
Nov/80	-12.7/+3.1		22.0/75	
Dec/80	-31.2/-7.4	-30.5/-	13.4/59	16.0/-
Jan/81	-12.8/+14.8	-12.3/-	13.4/96	7.7/-
Feb/81	-18.9/+4.6	-14.6/-	29.4/207	9.5/-
Mar/81	-9.3/+4.5	-4.1/-	13.9/124	6.0/-
Apr/81	-4.5/-2.0		63.5/418	
May/81	+11.7/+4.6		38.5/125	
Oct-May	+3.3		183 134.4	

[1] Reprinted from Atmospheric Environment Service, Monthly Record, Meteorological Observations, Northern Canada.

Table 2. Detailed stomach analysis for finescale dace, brook stickleback and slimy sculpin from Creeks Mile 48.9, 50.7 and 51.9, 1978. Food items as percent by number and occurrence of diet.

Creek Mile:	48.9								50.7				51.9					
Fish Species	Finescale dace				Brook Stickleback				Brook Stickleback				Slimy Sculpin					
Fish Length Interval (mm)	≤50		51-100		≤50		51-100		≤50		51-100		≤50		51-100		101-150	
Sampling Period	I		I		I		I		I		I		IV		IV		IV	
Fork Length Range	44-50		41-43		41-43		60-69		34-50		51-65		34-50		51-100		101-119	
No. Stomachs Analyzed/ No. Empty	8/7		11/4		3/3		8/3		4/0		3/0		21/4		26/2		10/0	
Mean No. Organisms/Stomach	2		10.1		0.0		15.2		21.5		10.0		10.5		4.2		5.6	
Food Item	% by Number	% by Occurrence																
Insecta																		
Diptera																		
larvae																		
Chironomidae	-	-	9.9	57.1	-	-	54.0	80.0	52.3	100.0	13.3	66.7	64.6	64.3	9.3	13.6	16.1	20.0
Simuliidae	-	-	26.8	57.1	-	-	5.3	60.0	3.5	75.0	16.7	66.7	0.7	7.1	-	-	-	-
Ceratopogonidae	-	-	4.2	42.9	-	-	-	-	5.8	75.0	3.3	33.3	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	0.7	7.1	1.1	4.6	1.8	10.0
Trichoptera																		
larvae	-	-	1.4	14.3			2.6	20.0	-	-	2.0	66.7	0.7	7.1	72.0	72.7	62.5	100.0
Plecoptera	100.0	100.0	57.8	100.0	-	-	21.0	80.0	18.6	75.0	36.7	66.7	1.4	14.3	-	-	-	-
Ephemeroptera	-	-	-	-	-	-	17.1	20.2	-	-	-	-	1.4	14.3	1.1	4.6	1.8	10.0
Coleoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	9.1	-	-
Odonata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	10.0
Crustacea																		
Ostracoda	-	-	-	-	-	-	-	-	7.0	50.0	6.7	33.3	19.1	42.9	1.1	4.6	-	-
Cladocera	-	-	-	-	-	-	-	-	12.8	75.0	3.3	33.3	11.6	14.3	7.5	9.1	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	9.1	-	-
Fish species																		
Slimy sculpin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	4.6	-	-
Longnose Sucker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.2	13.6	5.4	10.0
Unidentifiable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	10.0

Collection Dates: I May 23 - June 9
IV September 21 - 22

Table 3. Detailed stomach analysis for Arctic grayling from Creeks Mile 48.9 and 50.7, 1979. Food items as percent by number and occurrence of diet.

Creek Mile:	48.9				50.7					
Fish Length Interval (mm)	101 - 200				≤ 100		101 - 200			
Sampling Period	I		III		IV		III		IV	
Fork Length Range (mm)	180 - 186		191 - 199		64		172 - 179		133 - 183	
No. Stomachs Analyzed/ No. Empty	3/0		3/0		1/0		3/0		5/0	
Mean No. Organisms/Stomach	86.0		12.0		22.0		23.7		6.2	
Food Item	% by number	% by occurrence								
Insecta										
Diptera										
adults (unid)			8.3	33.3	68.2	100.0	25.4	100.0	25.8	20.0
larvae										
Chironomidae	77.5	33.3								
Ceratopogonidae							2.8	33.3		
Other	7.0	100.0	5.6	33.3			1.4	33.3		
Hymenoptera										
adults (unid)			13.9	33.3	13.6	100.0	1.4	33.3	12.9	20.0
Formicidae	1.2	66.7					4.2	66.7	6.5	40.0
Homoptera			8.3	33.3	18.2	100.0	18.3	100.0		
Hemiptera	0.8	66.7	44.4	100.0			18.3	100.0	3.2	20.0
Trichoptera										
adults							28.2	100.0	12.9	40.0
larvae	1.6	100.0							6.5	40.0
Coleoptera	0.8	33.3	8.3	66.7					6.5	40.0
Odonata	9.3	33.3	2.8	33.3					19.4	60.0
Plecoptera									3.2	20.0
Lepidoptera	0.4	33.3	2.8	33.3						
Orthoptera									3.2	20.0
Arachnida										
Acarina	0.4	33.3								
Araneida	0.4	33.3	5.6	33.3						
Nematomorpha	0.8	33.3								

Collection Dates: I May 17 - June 04
III August 19 - 20
IV September 08 - 10

Table 4. Detailed stomach analysis for Arctic grayling from Creeks Mile 48.9 and 50.7, 1980. Food items as percent by number and occurrence of diet.

Creek Mile:	48.9		50.7							
Fish Length Interval (mm)	100-200		100-200		201-300					
Sampling Period	I		I		I		II		IV	
Fork Length Range (mm)	155-190		168-197		204-207		215		203-225	
No. Stomachs Analyzed/ No. Empty	2/0		6/0		4/0		1/0		3/0	
Mean No. Organisms/Stomach	99.5		19.0		54.8		11.0		3.0	
Food Item:	**% by Number**	***% by occurrence***								
Insecta										
Diptera	-	-	-	-	-	-	-	-	-	-
adults (unid)	49.7	*100.0*	0.9	*16.7*	4.1	*50.0*	-	-	-	-
larvae	-	-	-	-	-	-	-	-	-	-
Chironomidae	40.7	*100.0*	53.5	*50.0*	35.2	*50.0*	-	-	-	-
Ceratopogonidae	9.0	*100.0*	11.4	*50.0*	36.1	*50.0*	-	-	-	-
Other	1.5	*50.0*	-	-	0.5	*25.0*	-	-	-	-
Hymenoptera										
adults (unid)	-	-	2.6	*16.7*	1.8	*25.0*	-	-	-	-
Formicidae	1.0	*50.0*	3.5	*50.0*	5.9	*75.0*	-	-	-	-
Hemiptera	-	-	2.6	*33.3*	0.5	*25.0*	-	-	-	-
Trichoptera										
adults	-	-	1.8	*16.7*	-	-	-	-	11.1	*33.3*
larvae	0.5	*50.0*	9.6	*50.0*	0.5	*25.0*	100.0	*100.0*	-	-
Coleoptera	1.5	*50.0*	7.9	*50.0*	7.3	*100.0*	-	-	22.2	*66.7*
Odonata	0.5	*50.0*	-	-	0.5	*25.0*	-	-	33.3	*33.3*
Arachnida										
Araneida	1.5	*50.0*	5.3	*50.0*	4.6	*50.0*	-	-	-	-
Fish Remains	-	-	0.9	*16.7*	3.2	*25.0*	-	-	33.3	*33.3*

Collection Dates: I May 10 - 23
II July 13 - 14
III August 17 - 18
IV September 16 - 18

Table 5. Detailed stomach analysis for brook stickleback, Creek Mile 48.9 Food items as percent by number and occurrence of diet Liard Highway Study, 1980.

Species: brook Stickleback	
Creek Mile: 48.9	
Fish Length Interval (mm)	≤50
Sampling Period	July 13-14
Fork Length Range (mm)	17-35
No. Stomachs Analyzed/ No. Empty	15/1
Mean No. Organisms/Stomach	15.2

Food Item:	% by Number	% by Occurrence
Insecta		
Diptera	-	-
Larvae	-	-
Chironomidae	9.4	64.3
Coleoptera	0.5	7.1
Crustacea		
Ostracoda	23.5	28.6
Copepoda	87.8	100.0

Table 6. Recapture data for Arctic grayling and longnose sucker from Creeks Mile 50.7 and 59.3, 1978-1981.

	Tag Data						Recapture Data					
	Location	Date	Fork L. (mm)	Weight (g)	Age (yrs.)	Maturity	Location	Date	Fork L. (mm)	Weight (g)	Age (yrs.)	Maturity
Tag Year 1978												
A. Grayling	Cr. Mi. 59.3	May 20	300	260	5	M4	Cr. Mi. 59.3	May 21/79	313	310	6	M4
	Cr. Mi. 59.3	May 21	266	170	4	--	Cr. Mi. 59.3	May 7/80	327	370	6 (7)*	M3
	Cr. Mi. 59.3	May 22	299	270	4	--	Cr. Mi. 59.3	May 8/80	286	220	5 (6)*	F3
							Cr. Mi. 59.3	Sept. 22/78	314	---	4	--
Tag Year 1979												
A. Grayling	Cr. Mi. 59.3	May 20	236	150	4	--	Cr. Mi. 51.9	May 13/80	269	195	5	--
L. Sucker	Cr. Mi. 50.7	May 25	369	500	-	--	Cr. Mi. 50.7	May 19/81	374	560	--	--
	Cr. Mi. 59.3	May 25	310	320	-	M4	Cr. Mi. 59.3	May 19/81	326	395	--	M3
	Cr. Mi. 59.3	May 28	336	480	-	--	Cr. Mi. 59.3	May 20/81	348	530	--	F3
Tag Year 1980												
A. Grayling	Cr. Mi. 50.7	May 10	294	275	5	--	Cr. Mi. 50.7	Sept. 18/80	299	300	5	--
	Cr. Mi. 50.7	May 10	262	192	5	--	Cr. Mi. 50.7	Sept. 18/80	271	215	5	--
	Cr. Mi. 51.9	May 8	270	205	4	--	Cr. Mi. 48.9	May 20/81	283	247	5	--
	Cr. Mi. 59.3	May 8	291	285	4	F4	Cr. Mi. 59.3	May 16/81	298	274	5	F4
L. Sucker	Cr. Mi. 51.9	May 10	321	385	--	M4	Cr. Mi. 51.9	May 18/81	321	375	--	M4

* Ages given are based on scale reading whereas ages enclosed in parenthesis represent theoretical ages.

Table 7. Detailed stomach analysis for Arctic grayling from Creek Mile 50.7, 1978. Food items as percent by number and occurrence of diet.

Creek Mileage 50.7												
Fish Length Interval (mm)	≤100				101-200				201-300			
Sampling Period	I		IV		I		IV		I		IV	
Fork Length Range (mm)	65-95		63		102-105		115-185		213-297		204-217	
No. Stomachs Analyzed/No. Empty	46/0		1/0		2/0		8/0		17/0		2/0	
Mean No. Organisms/Stomach	85.0		5.0		290.5		3.4		177.7		16.0	
Food Item	**% by number**	**% by occurrence**										
Insecta												
Diptera												
adults (unid)	0.8	17.4	-	-	0.5	50.0	7.4	12.5	4.5	58.8	37.5	50.0
larvae												
Chironomidae	78.4	100.0	80.0	100.0	92.5	100.0	3.7	12.5	41.9	100.0	-	-
Simuliidae	6.6	73.9	-	-	1 4	100.0	-	-	22.4	52.9	-	-
Ceratopogonidae	7.4	93.5	-	-	2.4	100.0	11.1	12.5	8.8	100.0	3.1	50.0
Other	0.8	23.9	-	-	0.3	50.0	-	-	0.9	52.9	-	-
Hymenoptera												
adults (unid)			-	-	-	-	3.7	12.5	0.2	10.2	3.1	50.0
Formicidae	0.2	8.7	-	-	-	-	-	-	1.6	52.9	-	-
Homoptera			20.0	100.0	-	-	18.5	50.0	0.1	11.8	25.0	50.0
Hemiptera	0.1	6.5	-	-	0.3	50.0	3.7	12.5	0.4	29.4	-	-
Trichoptera												
adults	-	-	-	-	-	-	11.1	25.0	0.1	11.8	-	-
larvae	2.2	52.2	-	-	0.5	100.0	14.8	25.0	6.4	100.0	21.9	100.0
Plecoptera	1.2	45.7	-	-	0.3	50.0	-	-	1.7	64.7	6.3	50.0
Ephemeroptera	0.1	8.7	-	-	-	-	-	-	0.1	64.7	-	-
Coleoptera	0.4	19.6	-	-	1.2	50.0	7.4	25.0	3.4	88.2	3.1	50.0
Orthoptera	-	-	-	-	-	-	-	-	0.1	11.8	-	-
Odonata			-	-	-	-	-	-	2.9	82.3	-	-
Lepidoptera	-	-	-	-	-	-	-	-	0.2	17.7	-	-
Arachnida												
Acarina	1.4	54.4	-	-	0.3	50.0	14.8	25.0	0.1	11.8	-	-
Araneida	0.4	15.2	-	-	0.2	50.0	3.7	12.5	2.7	64.7	-	-
Nematoda	-	-	-	-	-	-	-	-	0.3	29.4	-	-
Nematomorpha	-	-	-	-	-	-	-	-	1.4	41.2	-	-

Collection Dates: I: May 19 - June 02
IV: September 21 - 24.

Table 8. Fecundity measurements for Arctic grayling captured from Creek Mile 50.7, 1980.

	FISH			EGG		
Date	Length	Weight	Age	N	Mean Diameter(mm) Wet	Mean Weight (g) Wet/Dry
1. May 11	188	74	3	1433	1.972	0.0047/0.0016
2. May 11	175	56	3	886	1.868	0.0046/0.0017
3. May 11	178	52	3	649	2.000	0.0051/0.0016
4. May 15	177	N/A	3	681	1.976	0.0048/0.0015
5. Sept. 18	203	105	2	1460	1.385	0.0014/0.0006

Table 9. Detailed stomach analysis for Arctic grayling from Creek Mile 51.9, 1978. Food items as percent by number and occurrence of diet.

Creek Mile 51.9														
Fish Length Interval (mm)	≤100				101-200				201-300				301-400	
Sampling Period	I		I		I		IV		I		IV		I	IV
Fork Length Range	69-79		67-78		195-200		115-200		223-281		201-270		333	309
No. Stomachs Analyzed/														
No. Empty	5/0		3/0		2/0		11/0		17/0		8/0		1/0	1/0
Mean No. Organisms/Stomach	131.4		16.0		33.5		23.0		96.9		19.8		141.0	20.0
Food Item	% by Number	% by Occurrence												
Insecta														
Diptera														
adults (unid)	-	-	-	-	2.9	50.0	4.0	63.6	6.4	35.3	8.2	62.5	21.3 100.0	5.0 100.0
larvae														
Chironomidae	50.2	80.0	82.1	33.3	9.0	100.0	5.5	63.6	10.0	58.8	15.2	62.5	30.5 100.0	- -
Simuliidae	29.9	80.0	5.1	33.3	13.4	50.0	-	-	2.0	29.4	-	-	3.6 100.0	- -
Ceratopogonidae	2.0	60.0	7.7	33.3	1.5	50.0	0.4	9.1	1.9	64.7	2.5	25.0	3.6 100.0	- -
Other	-	-	-	-	7.5	50.0	0.4	9.1	1.1	35.1	-	-	0.7 100.0	- -
Hymenoptera														
adults (unid)	-	-	-	-	-	-	1.2	18.2	0.6	29.4	0.6	12.5	- -	- -
Formicidae	-	-	-	-	1.5	50.0	3.2	36.4	22.8	47.1	0.6	12.5	7.8 100.0	- -
Homoptera	0.2	20.0	-	-	-	-	1.2	18.2	0.3	11.8	1.3	25.0	-	- -
Hemiptera	-	-	2.6	33.3	3.0	50.0	49.4	100.0	1.9	47.1	32.9	100.0	0.7 100.0	45.0 100.0
Trichoptera														
adults	-	-	-	-	3.0	50.0	0.8	9.1	0.3	5.9	1.9	12.5	- -	- -
larvae	3.0	80.0	-	-	10.5	100.0	18.2	90.9	17.7	100.0	26.6	100.0	7.1 100.0	45.0 100.0
Plecoptera	0.2	20.0	-	-	4.5	100.0	0.8	18.2	0.9	47.1	-	-	- -	- -
Ephemeroptera	14.2	80.0	-	-	16.4	50.0	0.4	9.1	1.7	17.7	-	-	- -	- -
Coleptera	-	-	2.6	33.3	3.0	50.0	10.7	72.7	16.0	8.2	6.9	62.5	12.1 100.0	- -
Odonata	-	-	-	-	1.5	50.0	0.8	9.1	0.1	29.4	-	-	0.7 100.0	- -
Lepidoptera	-	-	-	-	-	-	0.4	9.1	0.5	29.4	1.3	12.5	- -	- -
Arachnida														
Acarina	0.2	20.0	-	-	1.5	50.0	0.4	9.1	0.1	5.9	-	-	- -	- -
Araneida	0.2	20.0	-	-	13.4	50.0	1.2	27.3	6.6	64.7	1.3	25.0	6.4 100.0	5.0 100.0
Nematoda	0.2	20.0	-	-	1.5	50.0	-	-	1.5	23.5	-	-	- -	- -
Nematomorpha	-	-	-	-	6.0	50.0	-	-	5.6	35.3	-	-	5.7 100.0	- -
Crustacea														
Ostracoda	-	-	Pres.[1]	33.3	-	-	Pres.[1]	54.6			Pres.[1]	100.0	- -	- -
Cladocera	Pres.[1]	80.0	-	-	-	-	Pres.[1]	36.4			Pres.[1]	87.5	- -	- -
Amphipoda	-	-	-	-	-	-	-	-			0.6		- -	- -
Mollusca														
Gastropoda	-	-	-	-	-	-	1.2	18.2	0.4		-	-	- -	- -

Collection Dates: I May 14 - June 7
IV September 21 - 22

[1]Pres. - Present, not counted.

Table 10. Suspended solids analysis from upstream and downstream sites for Creek Mile 51.9, 1979-1981.

Date	Discharge ($m^3 \cdot s^{-1}$)	Concentration ($g \cdot L^{-1}$)			Ratio
		Upstream	Downstream	Δ	Downstream/ Upstream
1979					
May 14/79	1.0	0.007	0.079	0.072	11.3
May 18/79	2.8	0.080	0.256	0.176	3.2
May 20/79	9.4	0.064	0.213	0.149	3.3
May 22/79	5.0	0.043	0.115	0.072	2.7
June 2/79	1.5	0.008	0.124	0.116	15.5
June 5/79	1.2	0.001	0.019	0.018	19.0
July 11/79	<0.10	0.001	0.014	0.013	14.0
Aug. 20.79	<0.10	0.008	0.031	0.023	3.1
Sept. 9/79	0.08	0.000	0.002	0.002	-
1980					
May 3/80	0.18	0.008	0.092	0.084	11.5
May 8/80	0.13	0.011	0.081	0.070	7.4
May 11/80	0.12	0.016	0.022	0.006	1.4
May 16/80	0.07	0.005	0.036	0.031	3.3
May 21/80	0.06	0.026	0.087	0.061	15.3
July 13/80	0.09	0.006	0.092	0.086	11.8
Aug. 8/80	0.01	0.004	0.047	0.043	11.8
Sept. 26/80	0.10	0.001	0.034	0.033	34.0
1981					
May 3/81	0.49	0.010	0.165	0.065	16.5
May 8/81	6.22	0.123	0.243	0.121	2.0
May 17/81	1.46	0.016	0.108	0.092	6.8

Table 11. Detailed stomach analysis for Arctic grayling from Creek Mile 51.9, 1979. Food items as percent by number and occurrence of diet.

Fish Length Interval (mm)	≤100				101 - 200				201 - 300				≥ 301	
Sampling Period	III		IV		I		IV		III		IV		I	
Fork Length Range (mm)	48		42 - 56		174		183 - 192		226 - 259		212 - 257		367	
No. Stomachs Analyzed/ No. Empty	1/0		2/0		1/0		5/0		6/0		2/0		1/0	
Mean No. Organisms/Stomach	1.0		2.5		30.0		19.2		16.2		32.5		39.0	
Food Item	% by Number	*% by Occurrence*												
Insecta														
Diptera														
adults (unid)			40.0	*50.0*			27.1	*60.0*	15.5	*33.3*				
pupae (unid)			60.0	*50.0*										
larvae														
Chironomidae					16.3	*100.0*	1.0	*20.0*					2.6	*100.0*
Simuliidae							1.0	*20.0*						
Ceratopogonidae					3.3	*100.0*							28.2	*100.0*
Other					53.3	*100.0*			1.0	*16.7*			2.6	*100.0*
Hymenoptera														
adults (unid)							6.3	*40.0*	6.2	*50.0*				
Formicidae							2.1	*40.0*	4.1	*16.7*	6.2	*100.0*		
Hemiptera	100.0	*100.0*					4.2	*60.0*	9.3	*66.7*	67.7	*100.0*	2.6	*100.0*
Trichoptera														
adults							18.8	*60.0*	1.0	*16.7*	3.1	*50.0*		
larvae					13.3	*100.0*	20.8	*100.0*	16.5	*50.0*	18.5	*50.0*	2.6	*100.0*
Coleoptera					3.3	*100.0*	2.1	*20.0*	17.5	*66.7*			10.3	*100.0*
Odonata					3.3	*100.0*	4.2	*40.0*	11.3	*66.7*			38.5	*100.0*
Lepidoptera									1.0	*16.7*	1.5	*50.0*		
Plecoptera							1.0	*20.0*						
Ephemeroptera									1.0	*16.7*				
Collembola							1.0	*20.0*	1.0	*16.7*				
Arachnida														
Araneida							2.1	*40.0*	8.2	*50.0*	3.1	*100.0*		
Nematoda					3.3	*100.0*								
Nematomorpha							1.0	*20.0*	5.2	*16.7*			2.6	*100.0*
Gastropoda							6.3	*20.0*	1.0	*16.7*				
Chilopoda					3.3	*100.0*	1.0	*20.0*						
Hirudinea													10.3	*100.0*

Collection Dates: I May 17 - June 4
III August 19 - 20
IV September 08 - 10

Table 12. Detailed stomach analysis for Arctic grayling from Creek Mile 51.9, 1980. Food items as percent by number and occurrence of diet.

Fish Length Interval (mm)	≤100				101-200				201-300								>301	
Sampling Period	III		IV		I		IV		I		II		III		IV		I	
Fork Length Range (mm)	44 - 69		66 - 79		169 - 199		183		210 - 267		213 - 217		204 - 287		210 - 213		312	
No. Stomachs Analyzed/ No. Empty (No. Unident.)	8/1 (3)		5/0 (3)		8/0		1/0		5/0		2/0		2/0		2/0		1/0	
Mean No. Organisms/Stomach	11.5		1.67		24.5		13.0		22.8		29.0		19.5		11.5		34.0	
	% by Number	% by Occurrence																
Food Item:																		
Insecta																		
Diptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
adults (unid)	-	-	-	-	1.5	12.5	-	-	-	-	29.3	50.0	5.1	50.0	-	-	-	-
larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae	45.9	75.0	-	-	16.3	25.0	-	-	5.3	20.0	1.7	50.0	-	-	-	-	-	-
Ceratopogonidae	-	-	-	-	1.0	12.5	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	27.0	25.0	-	-	5.6	12.5	-	-	-	-	-	-	-	-	-	-	-	-
Other	5.4	50.0	40.0	66.7	2.0	25.0	-	-	-	-	3.4	100.0	-	-	-	-	-	-
Hymenoptera																		
adults (unid)	5.4	50.0	-	-	0.5	12.5	84.6	100.0	0.9	20.0	6.9	50.0	2.6	50.0	4.3	50.0	-	-
Formicidae	-	-	-	-	13.8	75.0	7.7	100.0	5.3	60.0	3.4	50.0	-	-	4.3	50.0	50.0	100.0
Homoptera															4.3	50.0		
Hemiptera	-	-	-	-	6.6	50.0	-	-	27.2	80.0	5.2	50.0	10.3	100.0	4.3	50.0	5.9	100.0
Trichoptera																		
adults	2.7	25.0	20.0	33.3	-	-	-	-	-	-	-	-	-	-	47.8	50.0	-	-
larvae	2.7	25.0	40.0	33.3	6.1	50.0	7.7	100.0	18.4	80.0	36.2	100.0	10.3	50.0	21.7	100.0	23.5	100.0
Coleoptera	2.7	25.0	-	-	21.4	62.5	-	-	33.3	100.0	10.3	50.0	5.1	100.0	8.7	50.0	2.9	100.0
Odonata	-	-	-	-	2.0	25.0	-	-	-	-	3.4	100.0	17.9	50.0	13.0	50.0	14.7	100.0
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	50.0	-	-
Lepidoptera	-	-	-	-	0.5	12.5	-	-	-	-	-	-	-	-	-	-	-	-
Ephemeroptera	8.1	25.0	-	-	-	-	-	-	-	-	-	-	20.5	50.0	-	-	-	-
Arachnida																		
Araneida	-	-	-	-	20.4	50.0	-	-	5.3	20.0	-	-	2.6	50.0	-	-	2.9	100.0
Nematoda	-	-	-	-	-	-	-	-	0.9	20.0	-	-	-	-	-	-	-	-
Nematomorpha	-	-	-	-	-	-	-	-	3.5	20.0	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	25.6	50.0	4.5	50.0	-	-
Crustacea																		
Copepoda	Pres.[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladocera	Pres.[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Collection Dates: I May 04-23 III August 17-18
II July 13-14 IV September 16-18

[1] Pres. - Present, not counted.

Table 13. Detailed stomach analysis for slimy sculpin from Creek Mile 51.9, 1980. Food items as percent by number and occurrence of diet.

Creek Mile: 51.9								
Fish Length Interval	≤50		51-100				101-150	
Sampling Period	IV		I		IV		IV	
Fork Length Range (mm)	40-49		76-90		89		118	
No. Stomachs Analyzed/No. Empty	12/1		4/2		1/0		1/0	
Mean No. Organisms/Stomach	1.5		2.0		3.0		1.0	
Food Item:	% by Number	*% by Occurrence*						
Insecta								
Deptera	-	-	-	-	-	-	-	-
larvae	-	-	-	-	-	-	-	-
Chironomidae	47.1	*36.4*	-	-	-	-	-	-
Simuliidae	-	-	75.0	*50.0*	-	-	-	-
Other	29.4	*27.3*						
Trichoptera								
adults	5.9	*9.1*	-	-	-	-	-	-
larvae	11.8	*18.2*	-	-	-	-	-	-
Ephemeroptera	5.9	*9.1*	-	-	-	-	-	-
Nematoda	-	-	25.0	*50.0*	-	-	-	-
Crustacea								
Ostracoda	Pres.[1]	-	-	-	-	-	-	-
Fish Remains	-	-	-	-	100.0	*100.0*	100.0	*100.0*

Collection Dates: I: May 17 - 23
IV: September 16 - 18

[1] Pres. - Present, not counted.

Table 14. Detailed stomach analysis for Arctic grayling from Creek Mile 59.3, 1978. Food items as percent by number and occurrence of diet.

Fish Length Interval (mm)	≤100		101 - 200		201 - 300				301 - 400	
Sampling Period	IV		IV		I		IV		I	
Fork Length Range	38-84		120-140		218 - 300		214 - 248		305-316	
No. Stomachs Analyzed/ No. Empty	34/4		7/1		18/0		2/1		3/0	
Mean No. Organisms/Stomach	25.2		3.3		32.4		29.0		13.0	
Food Item	**% by Number**	***% by Occurrence***								
Insecta										
Diptera										
adults (unid)	2.9	*16.7*	-	-	11.1	*5.6*	-	-	-	-
larvae										
Chironomidae	36.3	*80.0*	4.4	*16.7*	14.6	*61.1*	-	-	10.3	*66.7*
Simuliidae	1.1	*6.7*	-	-	0.2	*5.6*	-	-	-	-
Ceratopogonidae	1.8	*10.0*	-	-	2.4	*61.1*	-	-	2.6	*33.3*
Other	5.0	*26.7*	-	-	2.6	*55.6*	-	-	7.7	*66.7*
Hymenoptera										
adults (unid)	2.9	*16.7*	-	-	-	-	-	-	-	-
Formicidae	-	-	-	-	3.9	*5.6*	-	-	-	-
Homoptera	0.4	*6.7*	8.7	*16.7*	0.3	*11.1*	-	-	-	-
Hemiptera	1.4	*10.0*	13.0	*16.7*	2.4	*44.4*	1.7	*100.0*	5.1	*33.3*
Trichoptera										
adults	1.1	*10.0*	4.4	*16.7*	-	-	-	-	-	-
larvae	19.1	*53.3*	56.5	*100.0*	44.4	*100.0*	96.6	*100.0*	71.8	*100.0*
Plecoptera	21.9	*40.0*	4.4	*16.7*	0.9	*22.2*	-	-	-	-
Ephemeroptera	1.1	*6.7*	-	-	-	-	-	-	-	-
Coleoptera	1.4	*20.0*	8.7	*33.3*	10.8	*44.4*	-	-	-	-
Odonata	-	-	-	-	1.4	*38.9*	1.7	*100.0*	2.6	*33.3*
Arachnida										
Acarina	4.3	*30.0*	-	-	-	-	-	-	-	-
Araneida	1.4	*6.7*	-	-	2.4	*33.3*	-	-	-	-
Nematoda	0.7	*6.7*	-	-	1.2	*16.9*	-	-	-	-
Nematomorpha	-	-	-	-	0.3	*11.1*	-	-	-	-
Crustacea										
Ostracoda	Pres.[1]	*6.7*	-	-	-	-	-	-	-	-
Cladocera	Pres.[1]	*43.3*	-	-	-	-	-	-	-	-
Annelida										
Oligochaeta	0.4	*3.3*	-	-	-	-			-	-

Collection Dates: I May 15 - June 6
IV September 21 - 22

[1]Pres. - Present, not counted

Table 15. Detailed stomach analysis for Arctic grayling from Creek Mile 59.3, 1979. Food items as percent by number and occurrence of diet.

Creek Mile - 59.3																								
Fish Length Interval (mm)	≤100						101 - 200								201 - 300						301 - 400			
Sampling Period	II		III		IV		I		II		III		IV		I		II		III		I		IV	
Fork Length Range (mm)	26 - 43		38 - 68		47 - 62		197		171		151 - 180		118		216 - 298		261		288		321		302	
No. Stomachs Analyzed/ No. Empty	38/0		29/0		10/0		1/0		1/0		4/1		1/0		10/0		1/0		1/0		1/0		1/0	
No. Organisms/Stomach	7.5		7.2		5.4		46.0		11.0		11.3		12.0		16.6		21.0		5.0		26.0		36.0	
Food Item	% by Number	% by Occurrence																						
Insecta																								
Diptera																								
adults (unid)	4.2	18.4	10.5	23.1	24.1	40.0	-	-	45.5	100.0	-	-	-	-	0.6	10.0	-	-	-	-	-	-	-	-
pupae (unid)	30.1	42.1	19.5	41.3	16.7	20.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
larvae																								
Chironomidae	24.5	57.9	19.0	44.8	25.9	40.0	-	-	-	-	-	-	-	-	21.1	90.0	-	-	-	-	3.8	100.0	-	-
Simuliidae	2.1	10.5	22.4	31.0	-	-	-	-	-	-	-	-	-		-	-	14.3	100.0	-	-	-	-	-	-
Ceratopogonidae	1.7	7.9	0.5	3.4	-	-	-	-	-	-	-	-	-	-	3.0	40.0	4.8	100.0	-	-	-	-	-	-
Other	1.0	7.9	1.0	10.3	-	-	17.4	100.0	-	-	-	-	-	-	13.3	70.0	-	-	-	-	-	-	-	-
Hymenoptera																								
adults (unid)	-	-	-	-	3.7	20.0	-	-	-	-	2.2	50.0	-	-	-	-	-	-	20.0	100.0	-	-	-	-
Formicidae	-	-	1.0	6.9	-	-	-	-	-	-	15.6	50.0	-	-	1.2	20.0	23.8	100.0	20.0	100.0	-	-	-	-
Homoptera	7.3	26.3	3.3	20.7	1.9	10.0	-	-	9.1	100.0	-	-	-	-	0.6	10.0	4.8	100.0	-	-	-	-	-	-
Hemiptera	0.4	2.6	2.9	17.2	1.9	10.0	45.7	100.0	9.1	100.0	17.8	50.0	-	-	10.8	50.0	4.8	100.0	40.0	100.0	-	-	33.3	100.0
Trichoptera																								
adults	-	-	2.9	20.9	-	-	-	-	-	-	6.6	25.0	-	-	-	-	-	-	-	-	-	-	-	-
larvae	1.4	10.5	2.9	20.9	18.5	40.0	19.7	100.0	-	-	53.3	50.0	100.0	100.0	27.1	90.0	19.0	100.0	-	-	92.3	100.0	66.7	100.0
Plecoptera	1.0	7.9	4.3	27.6	3.7	40.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemeroptera	25.8	55.3	2.4	17.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coleoptera	0.4	2.6	1.4	10.3	3.7	20.0	2.2	100.0	18.2	100.0	-	-	-	-	3.0	20.0	19.0	100.0	-	-	-	-	-	-
Odonata	-	-	0.5	3.4	-	-	-	-	18.2	100.0	2.2	25.0	-	-	3.0	40.0	9.5	100.0	20.0	100.0	3.8	100.0	-	-
Lepidoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	10.0	-	-	-	-	-	-	-	-
Arachnida																								
Acarina	-	-	4.3	6.9	-	-	-	-	-	-	2.2	25.0	-	-	0.6	10.0	-	-	-	-	-	-	-	-
Araneida	-	-	1.4	6.9	-	-	-	-	-	-	-	-	-	-	4.8	20.0	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	2.2	100.0	-	-	-	-	-	-	3.0	30.0	-	-	-	-	-	-	-	-
Nematomorpha	-	-	-	-	-	-	6.5	100.0	-	-	-	-	-	-	7.2	20.0	-	-	-	-	-	-	-	-
Crustacea																								
Cladocera	Pres.[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Pres.[1]	-
Chilopoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	10.0	-	-	-	-	-	-	-	-
Pelecypoda	-	-	-	-	-	-	6.5	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish Remains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Pres.[1]		-	-

Collection Dates: I May 17 - June 4
II July 10-11
III August 19-20
IV September 8-10

[1] Pres. - Present, not counted

Table 16. Suspended solids analysis from upstream and downstream sites for Creek Mile 59.3, 1979-1981.

Date	Discharge ($m^3 \cdot s^{-1}$)	Concentration ($g \cdot L^{-1}$)			Ratio
		Upstream	Downstream	Δ	Downstream/ Upstream
1979					
May 14/79	0.55	0.024	0.059	0.035	2.5
May 19/79	2.80	0.153	0.247	0.094	1.6
June 5/79	≈0.75	0.008	0.025	0.017	3.1
July 11/79	-	0.003	0.017	0.004	5.7
Aug. 20/79	-	0.005	0.013	0.008	2.6
Sept. 8/79	0.05	0.004	0.003	0.001	.75
1980					
May 3/80	0.10	0.015	0.020	0.005	1.3
May 8/80	0.10	0.004	0.009	0.005	2.3
May 11/80	0.09	0.002	0.014	0.012	7.0
May 16/80	0.07	0.001	0.026	0.025	26.0
May 21/80	0.07	0.001	0.005	0.004	5.0
July 13/80	0.15	0.003	0.010	0.007	3.3
Aug. 18/80	0.01	0.002	0.007	0.005	3.5
Sept. 16/80	0.09	0.002	0.006	0.004	3.0
1981					
May 4/81	0.86	0.014	0.118	0.104	8.4
May 8/81	≈3.00	0.125	0.290	0.165	2.3
May 18/81	≈0.70	0.013	0.024	0.011	1.8

Table 17. Detailed stomach analysis for Arctic grayling from Creek Mile 59.3, 1980. Food items as percent by number and occurrence of diet.

Creek Mile - 59.3																		
Fish Length Interval (mm)	≤100						101 - 200				201 - 300							
Sampling Period	II		III		IV		I		III		I		II		III		IV	
Fork Length Range (mm)	38 - 58		53 - 69		56 - 78		177 - 188		173		203 - 237		208 - 221		214		208 -237	
No. Stomachs Analyzed/ No. Empty	24/0		12/0,(1)		16/0,(1)		8/0		1/0		8/0		3/0		1/0		4/0	
No. Organisms/Stomach	27.5		7.4		16.7		24.9		10.0		15.0		23.3		23.0		9.5	
Food Item	% by Number	% by Occurrence																
Insecta																		
Diptera																		
adults (unid)	-	-	-	-	0.8	6.3	7.0	12.5	20.0	100.0	-	-	5.7	66.7	-	-	2.6	25.0
larvae																		
Chironomidae	87.6	100.0	53.5	66.7	80.5	93.8	1.5	12.5	-	-	4.2	25.0	1.4	33.3	-	-	7.9	25.0
Simuliidae	-	-	10.1	16.7	0.4	6.3	-	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	0.6	12.5	3.7	25.0	4.1	25.0	-	-	-	-	2.5	12.5	-	-	-	-	2.6	25.0
Other	4.1	58.3	1.1	18.8	3.0	50.0	-	-	8.3	50.0	2.9	33.3	-	-	-	-	-	-
Hymenoptera																		
adults (unid)	0.2	4.2	-	-	-	-	3.0	25.0	-	-	-	-	7.1	66.7	-	-	-	-
Formicidae	0.2	4.2	-	-	-	-	6.5	75.0	10.0	100.0	8.3	37.5	17.1	33.3	-	-	-	-
Homoptera	0.5	4.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiptera	0.2	4.2	-	-	-	-	5.0	62.5	-	-	16.6	75.0	20.0	100.0	78.3	100.0	42.1	100.0
Trichoptera																		
adults	0.2	4.2	1.1	8.3	2.3	25.0	-	-	-	-	-	-	-	-	-	-	-	-
larvae	0.9	16.4	1.1	8.3	2.6	37.5	24.1	87.5	60.0	100.0	33.3	87.5	18.6	66.7	8.7	100.0	13.2	50.0
Plecoptera	1.1	25.0	2.3	16.7	4.1	37.5	0.5	12.5	-	-	-	-	4.3	33.3	-	-	2.6	25.0
Ephemeroptera	1.1	28.8	13.5	41.9	1.5	25.0	-	-	-	-	-	-	-	-	-	-	-	-
Coleoptera	0.9	16.4	1.1	8.3	-	-	33.7	100.0	-	-	22.5	62.5	15.7	100.0	-	-	23.7	75.0
Odonata	-	-	-	-	-	-	1.0	12.5	10.0	12.5	-	-	-	-	4.3	100.0	2.6	25.0
Collembola	-	-	-	-	0.4	6.3	-	-	-	-	-	-	-	-	-	-	-	-
Arachnida																		
Araneida	0.2	4.2	-	-	-	-	9.5	100.0	-	-	1.7	25.0	-	-	-	-	-	-
Acarina	-	-	14.6	50.0	1.9	18.8	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.6	25.0
Nematoda	2.6	41.7	-	-	0.4	6.3	2.0	25.0	-	-	1.7	25.0	-	-	8.7	100.0	-	-
Nematomorpha	-	-	-	-	-	-	3.0	37.5	-	-	-	-	-	-	-	-	-	-
Crustacea																		
Cladocera	-	-	-	-	Pres.[1]	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	Pres.[1]	-	Pres.[1]	-	Pres.[1]	-	-	-	-	-	-	-	-	-	-	-	-	-

Collection Dates: I May 4-23
II July 13-14
III August 17-18
IV September 16-18

[1] Pres. - Present, not counted

Table 18. Relationship between fork length, weight, and critical velocity for four species of Mackenzie River fish (condensed from Jones et al. 1974).

Species	n	Length range (cm)	Weight range (g)	Condition factor[1]	Weight/Length correlation coefficient	Length-velocity regression (V=KL^e) K	e	velocity correlation coefficient	P-value for correlation coefficient	Remarks
Pike	192	12.0-62.0	7-1800	0.66±0.01	0.96	4.9	0.55	0.441	0.001	Regression on 12°C lab data only - insufficient numbers in other groups
Grayling	94	7.0-37.0	1.5-800	1.03±0.02	0.97	36.23	0.19	0.221	0.02	Includes all groups except 7°C lab data
	11	21.0-34.0	90-500	1.02±0.03		91.64	0.14	0.104	0.1	
Longnose sucker	169	4.0-53.0	0.5-2200	1.03±0.01	0.96	11.03	0.53	0.787	0.0001	All groups pooled after ANCOVA showed no significant group differences
White sucker	20	17.0-37.0	50-550	1.37±0.21	0.90	10.03	0.55	0.501	0.02	No lab data - field data pooled after ANCOVA showed no significant group differences

[1] Condition factor = $\frac{100\ W}{L^3}$ where W = weight (g), L = length (cm).

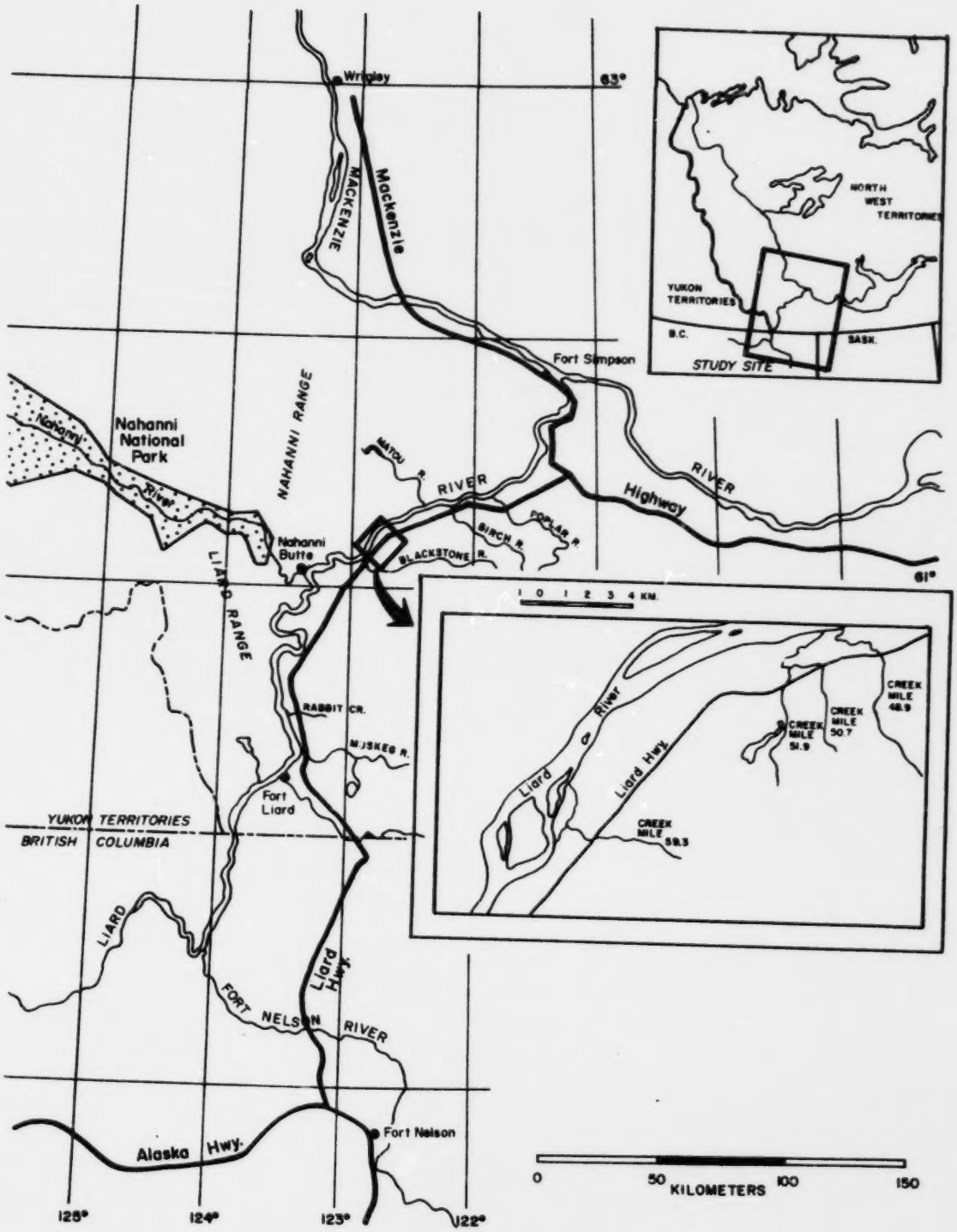

Fig. 1. Map of study area showing the Liard Highway alignment.

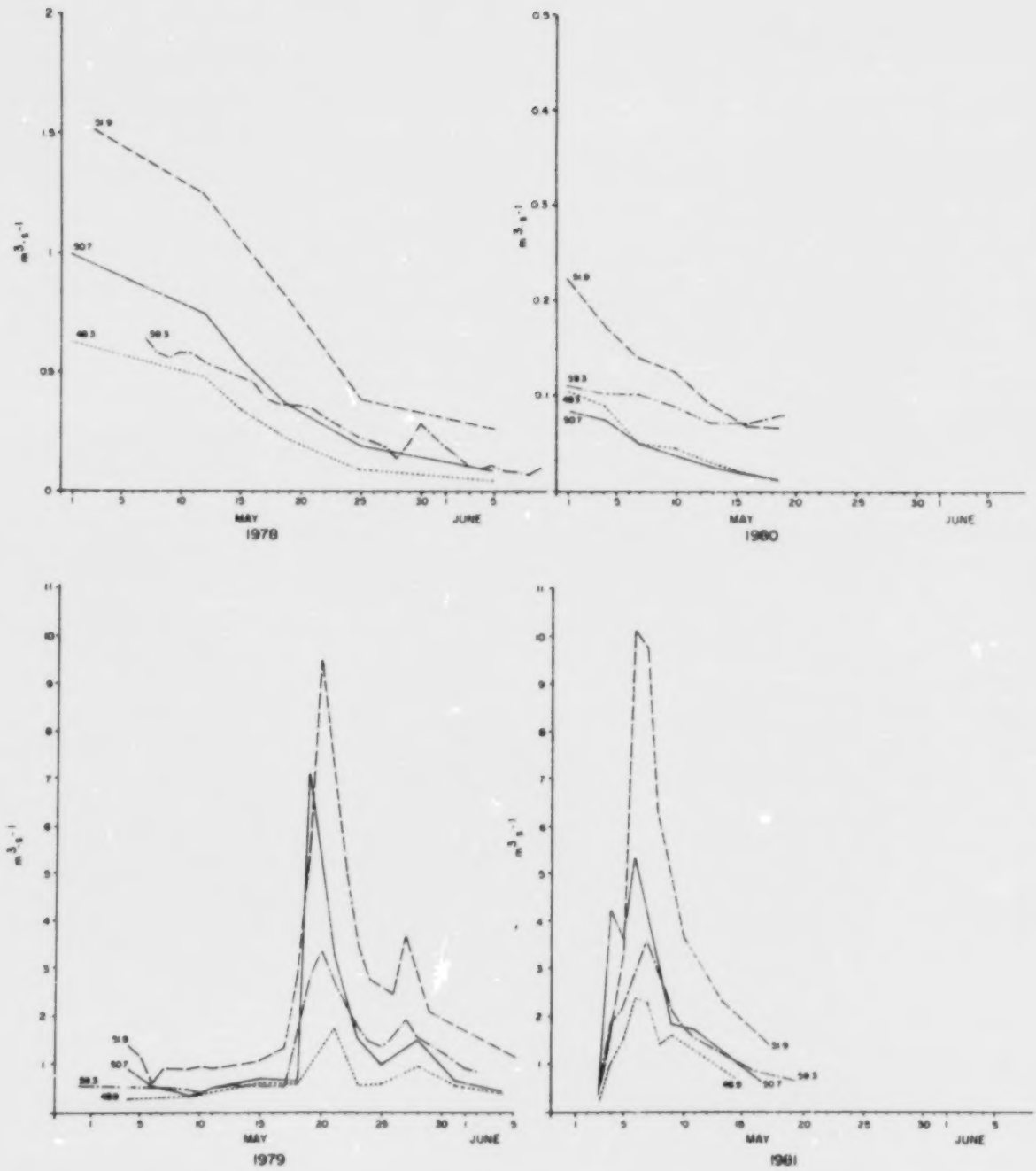

Fig. 2. Stream hydrographs for Creek Mile 48.9, Creek Mile 50.7, Creek Mile 51.9 and Creek Mile 59.3, 1978-1981.

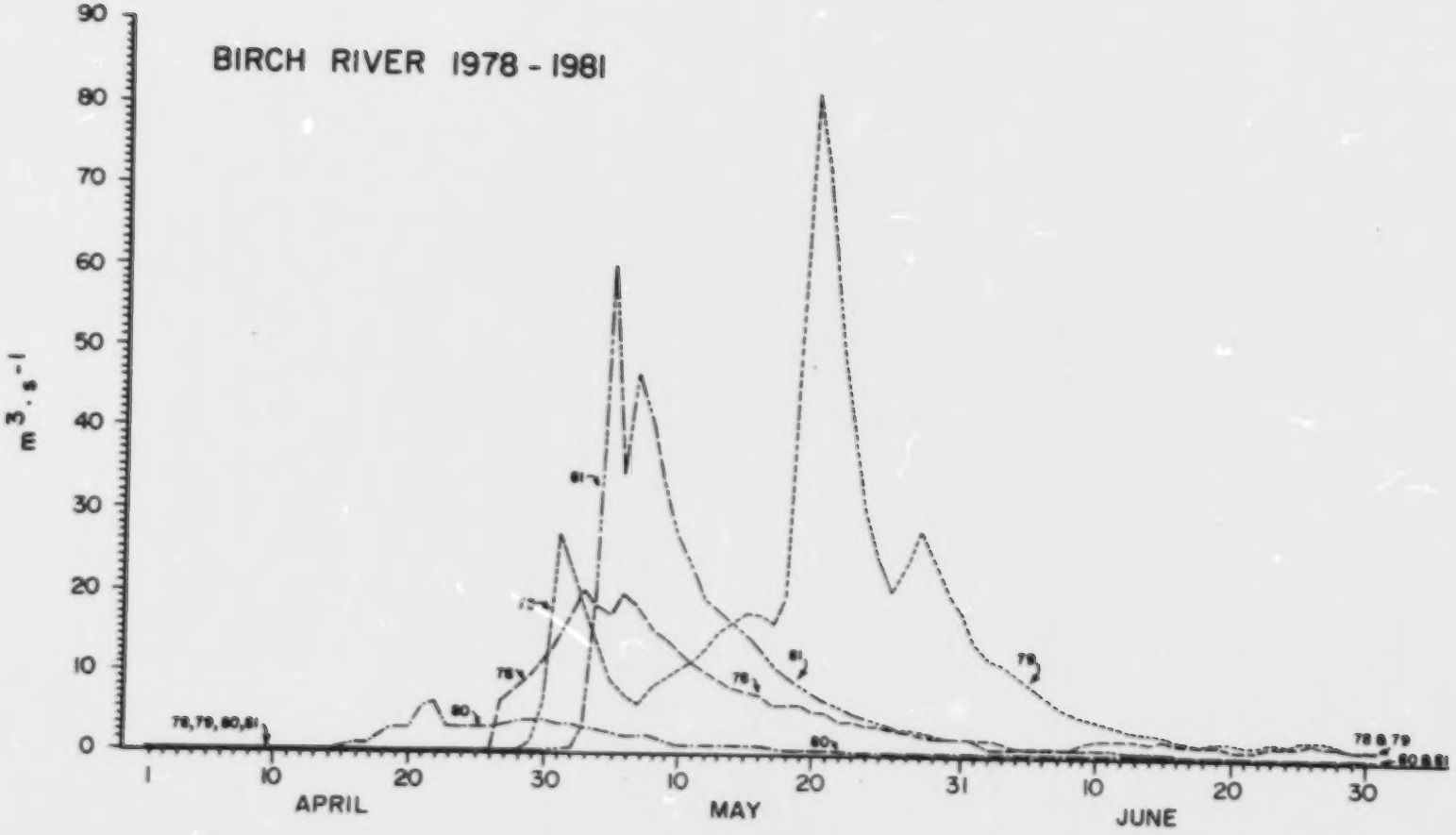

Fig. 3. Birch River hydrograph 1978-1981.

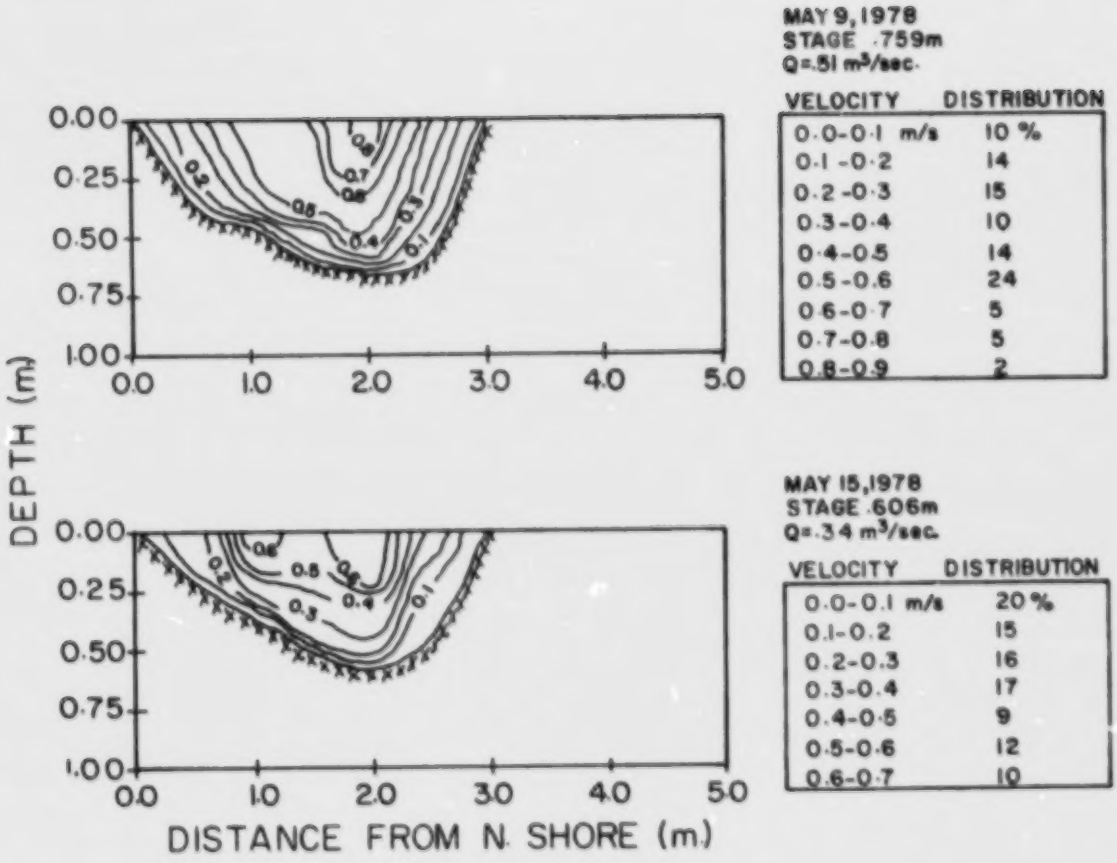

Fig. 4. Cross-sectional water velocity profiles for the natural stream channel of Creek Mile 48.9 at the highway alignment, 1978.

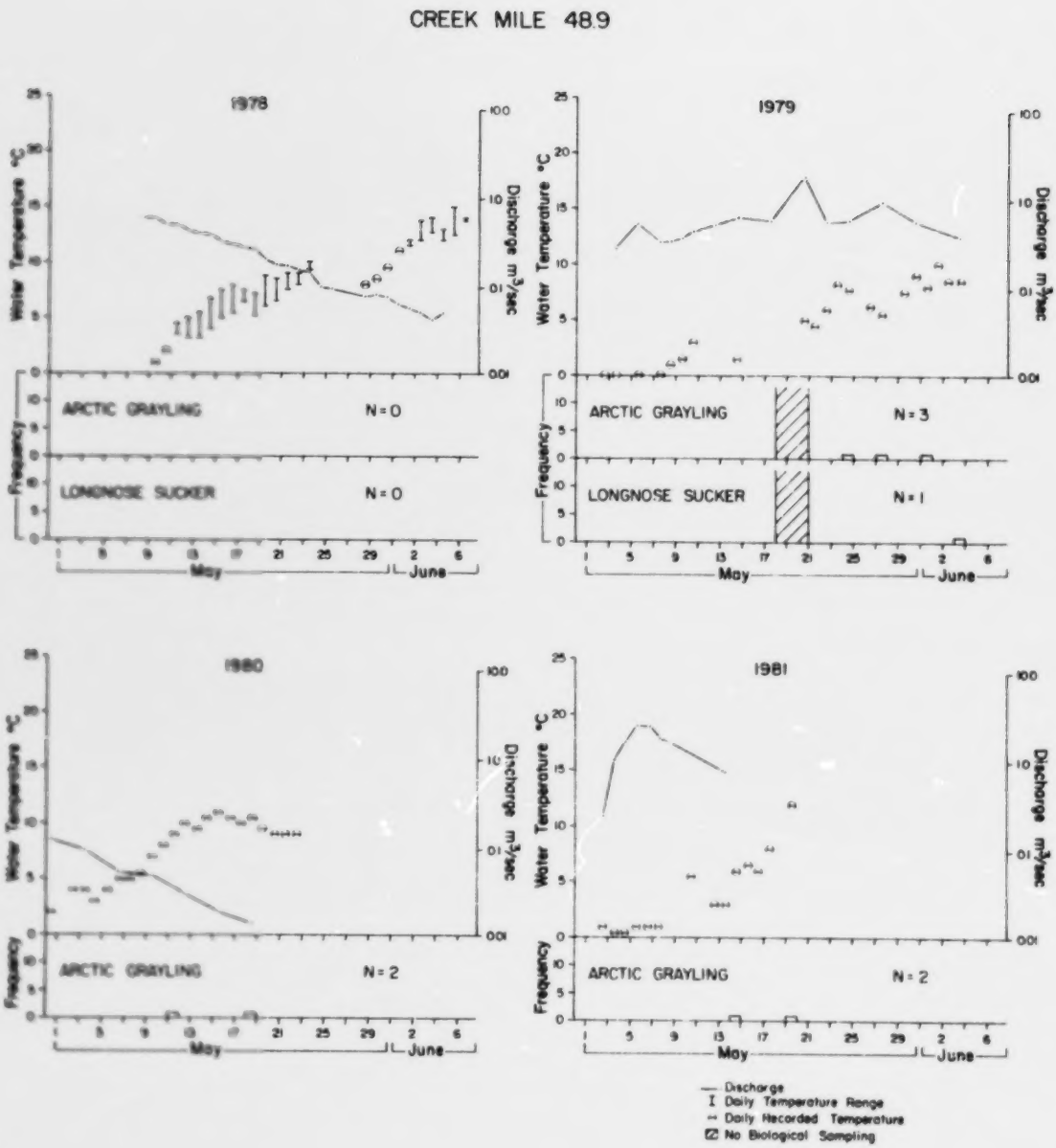

Fig. 5. Calendar catch frequency for Arctic grayling and longnose sucker upstream migrants as compared to hydrograph and water temperature, Creek Mile 48.9, 1978-1981.

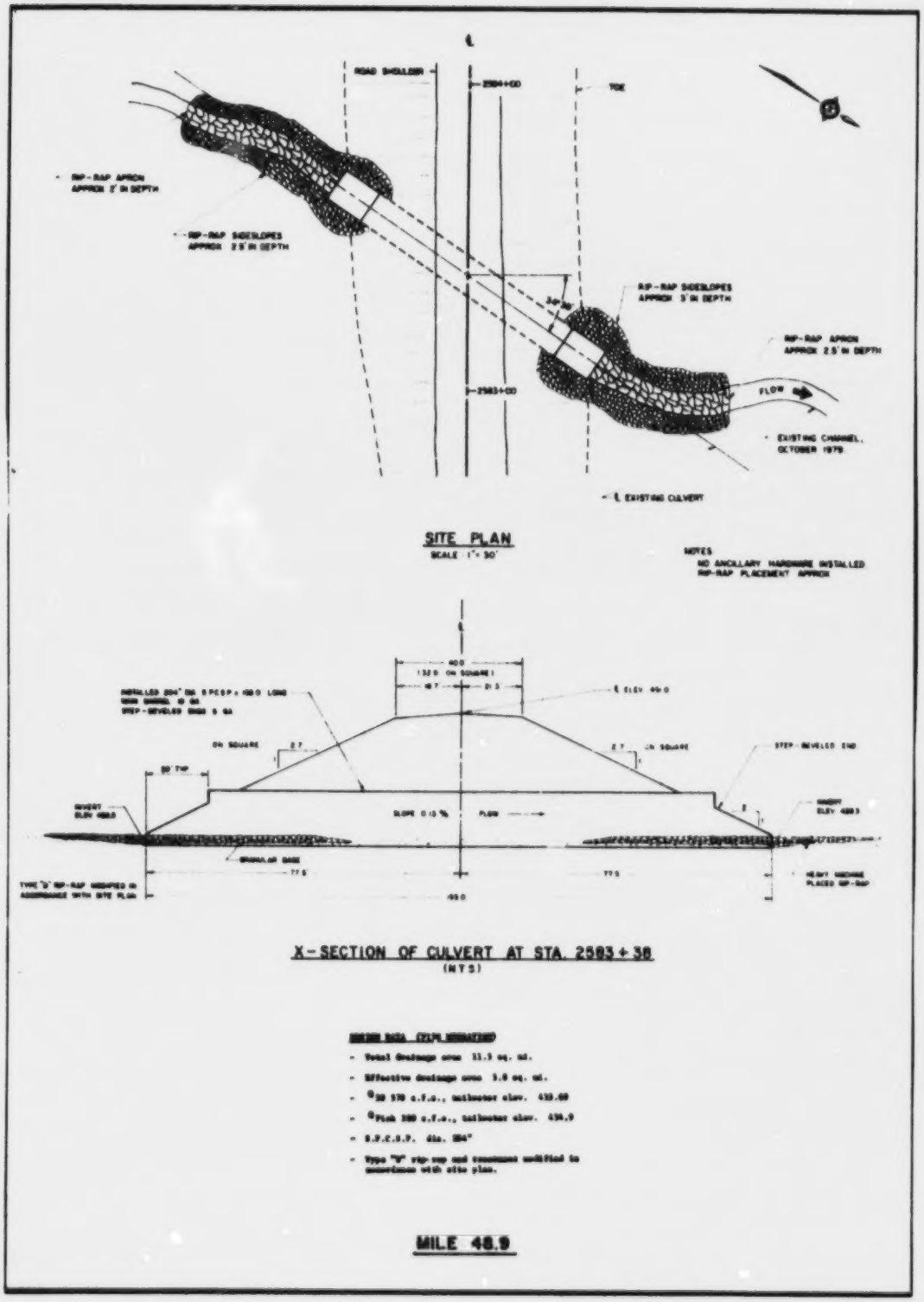

Fig. 6. Site plan of the culvert installation at Creek Mile 48.9.

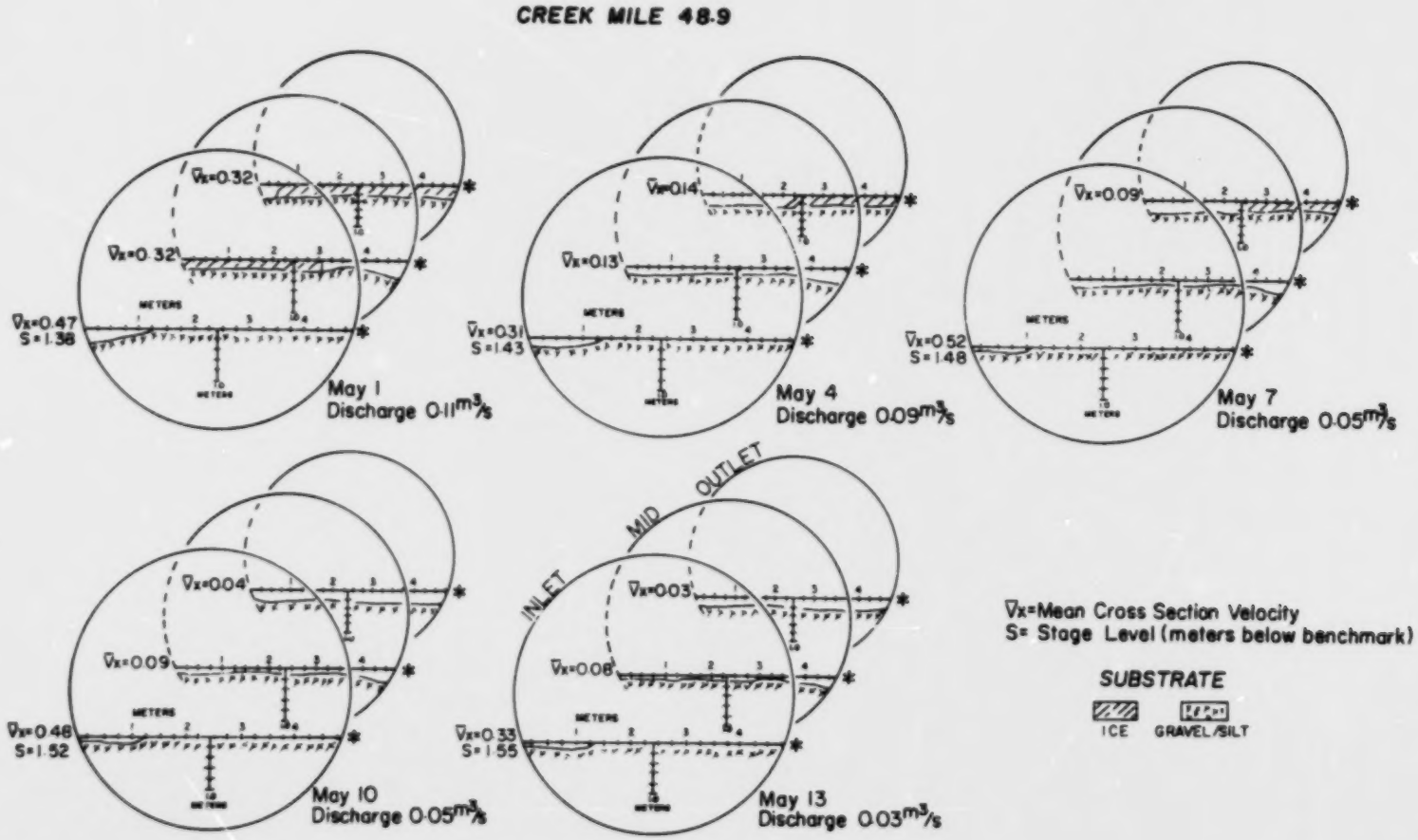

Fig. 7. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 48.9, 1980.

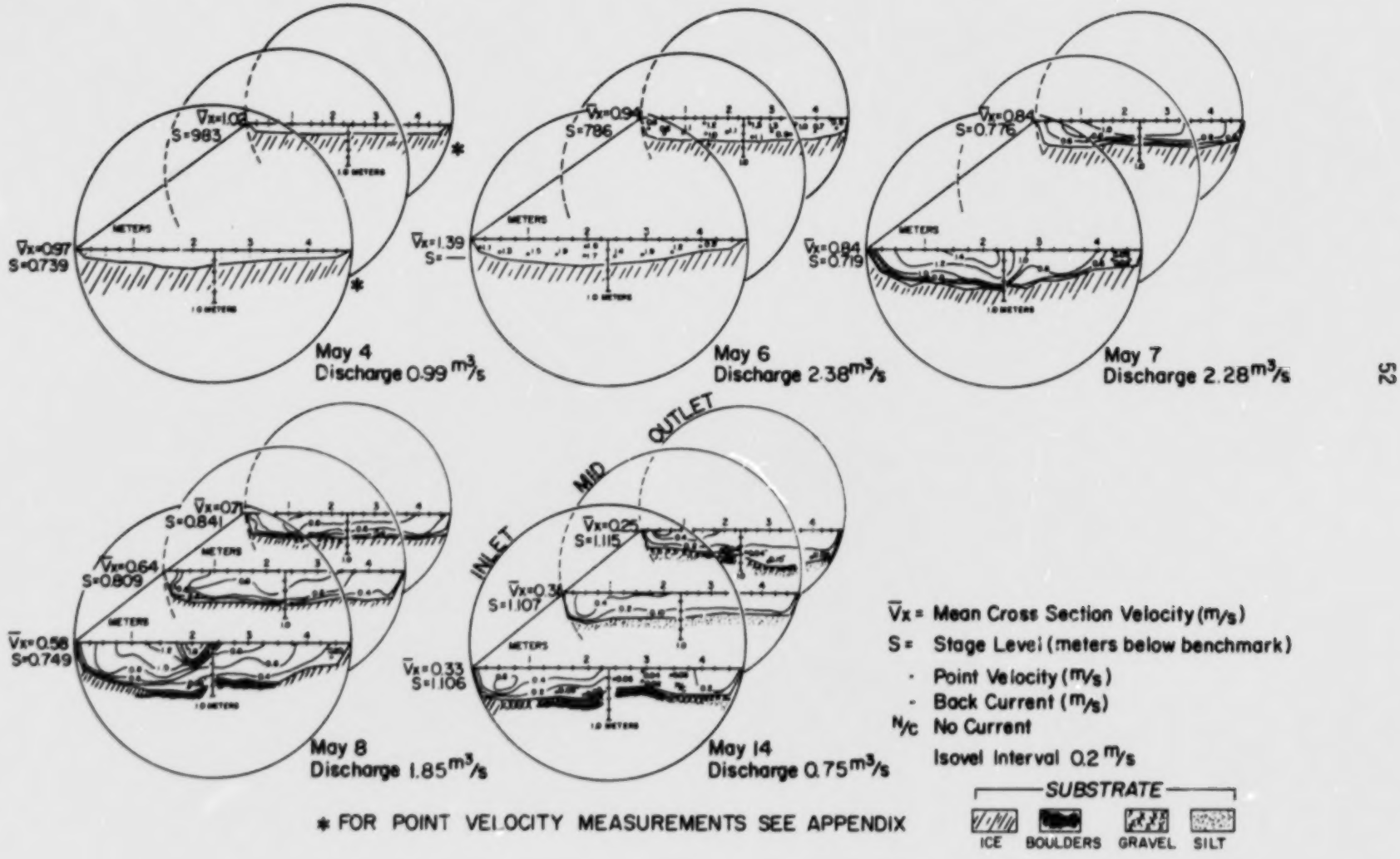

Fig. 8. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 48.9, 1981.

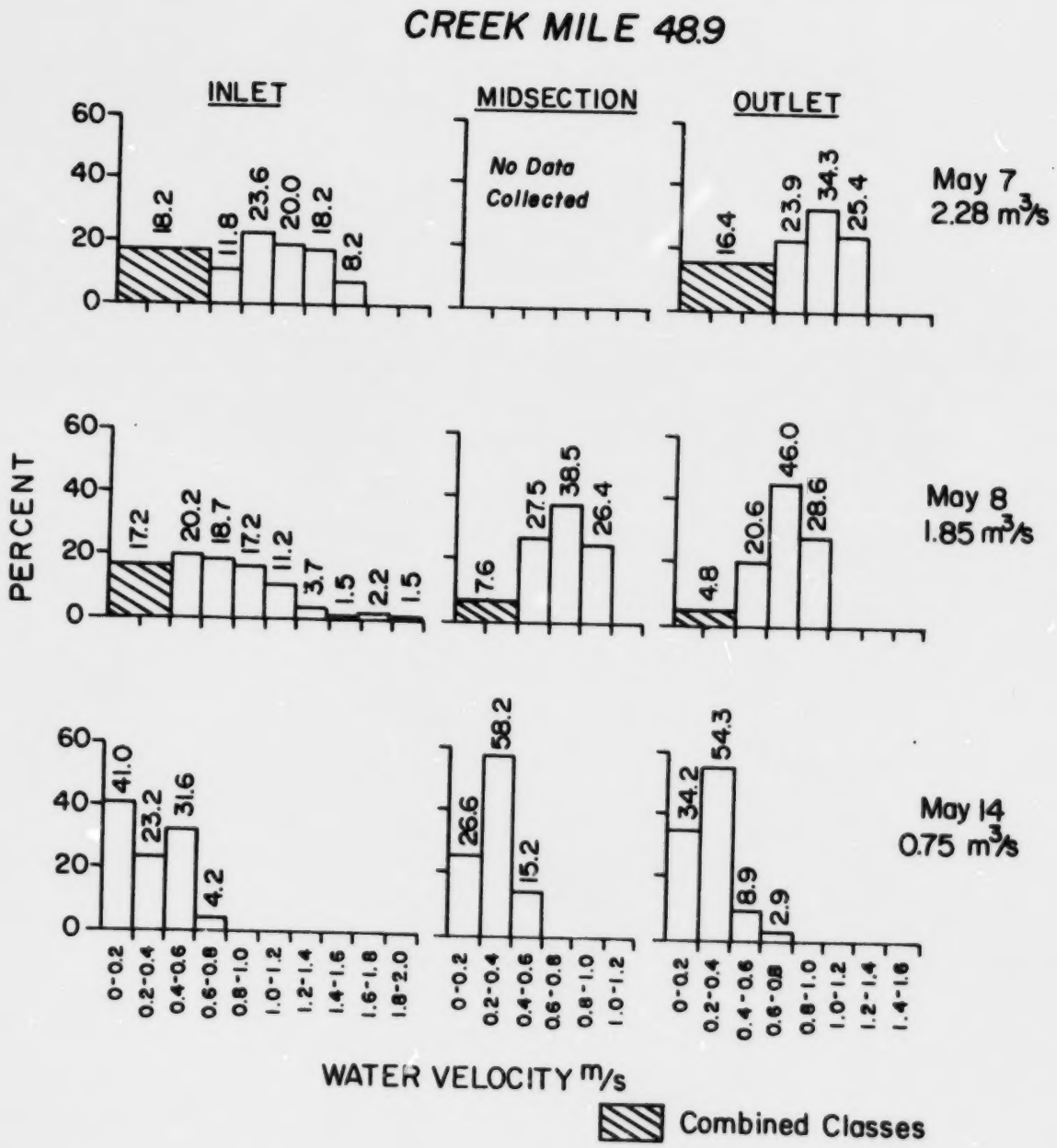

Fig. 9. Cross-sectional water velocity distribution for the culvert installation at Creek Mile 48.9, 1981.

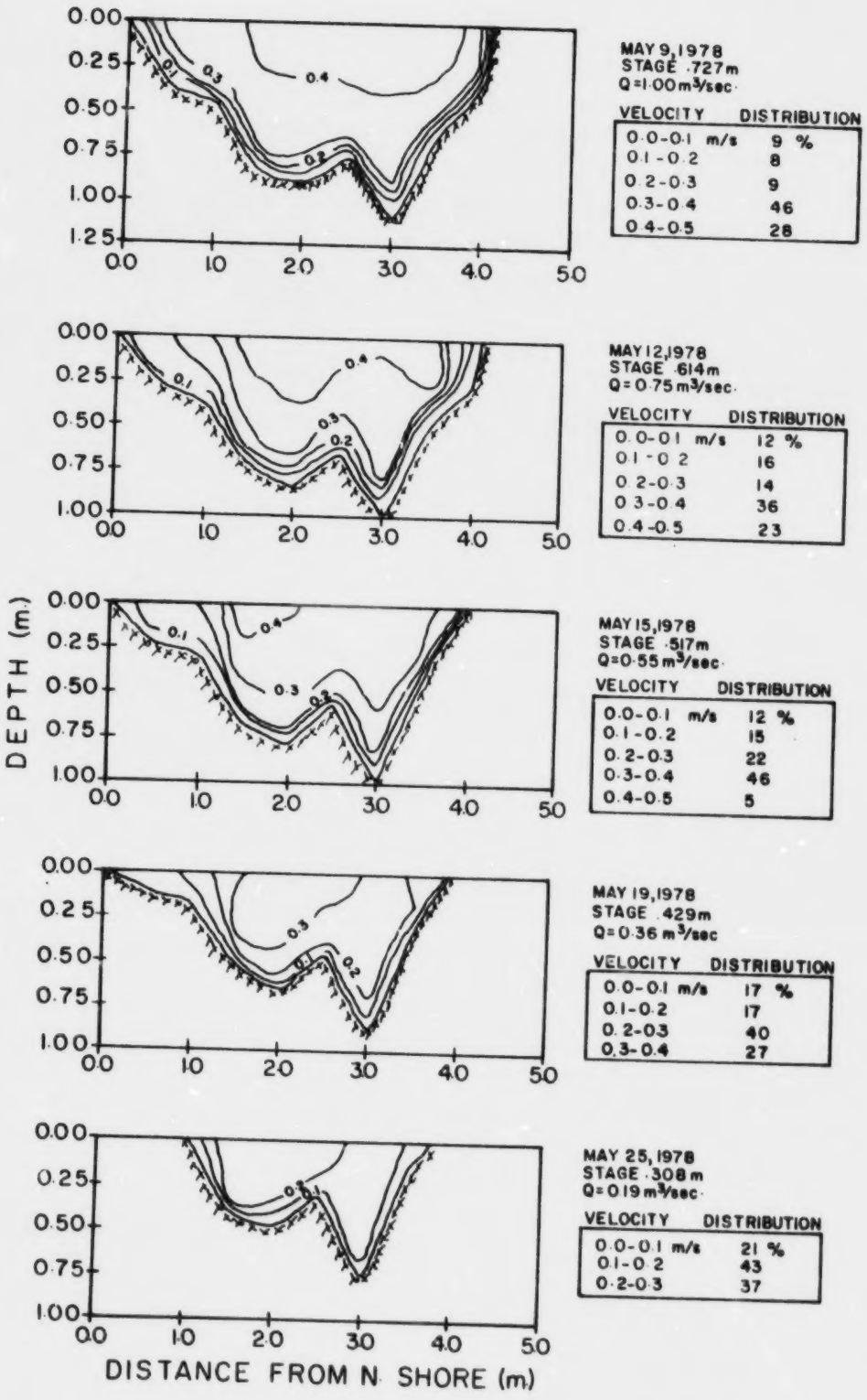

Fig. 10. Cross-sectional water velocity profiles for the natural stream channel of Creek Mile 50.7 at the highway alignment, 1978.

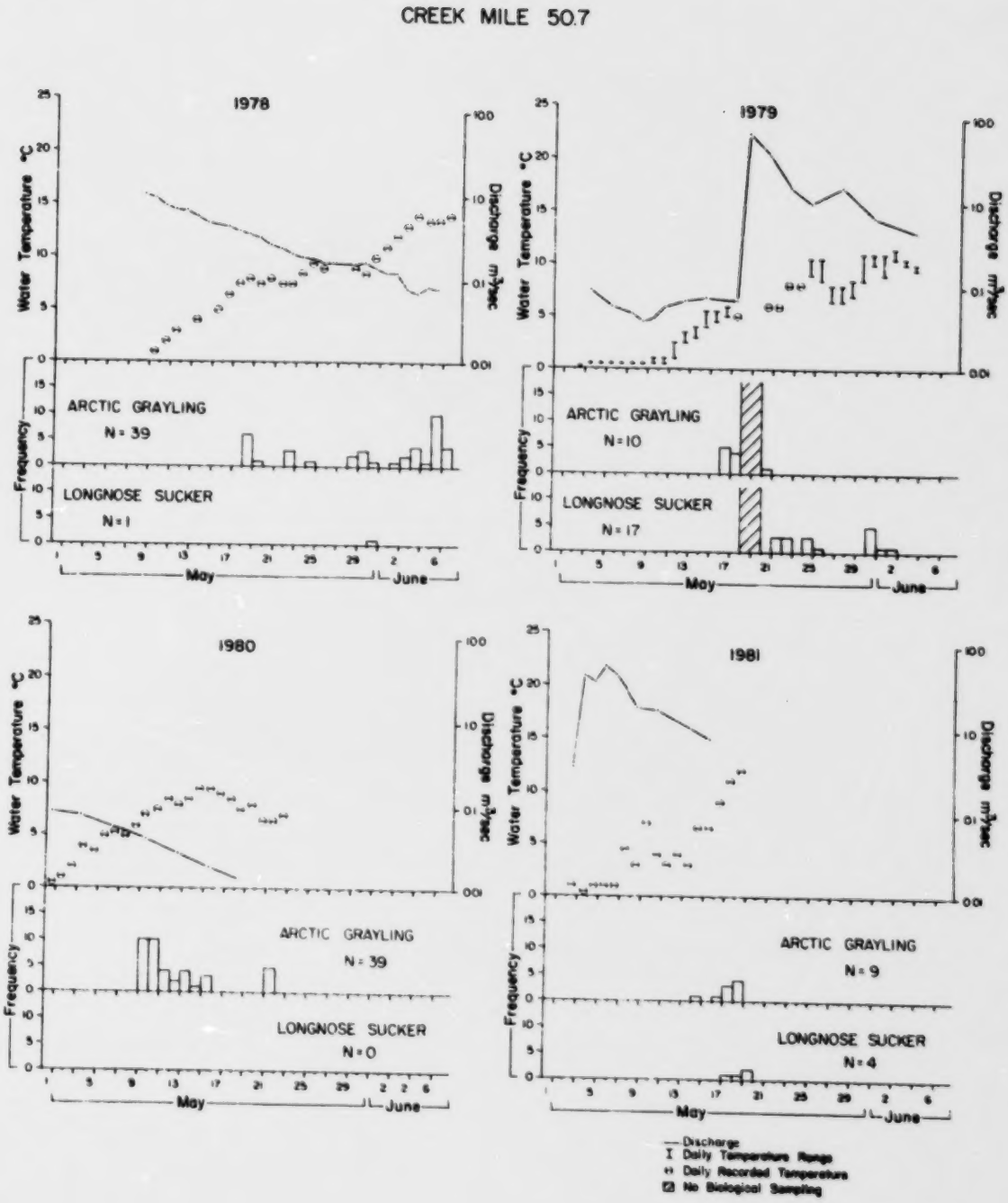

Fig. 11. Calendar catch frequency for Arctic grayling and longnose sucker upstream migrants as compared to hydrograph and water temperature, Creek Mile 50.7, 1978-1981.

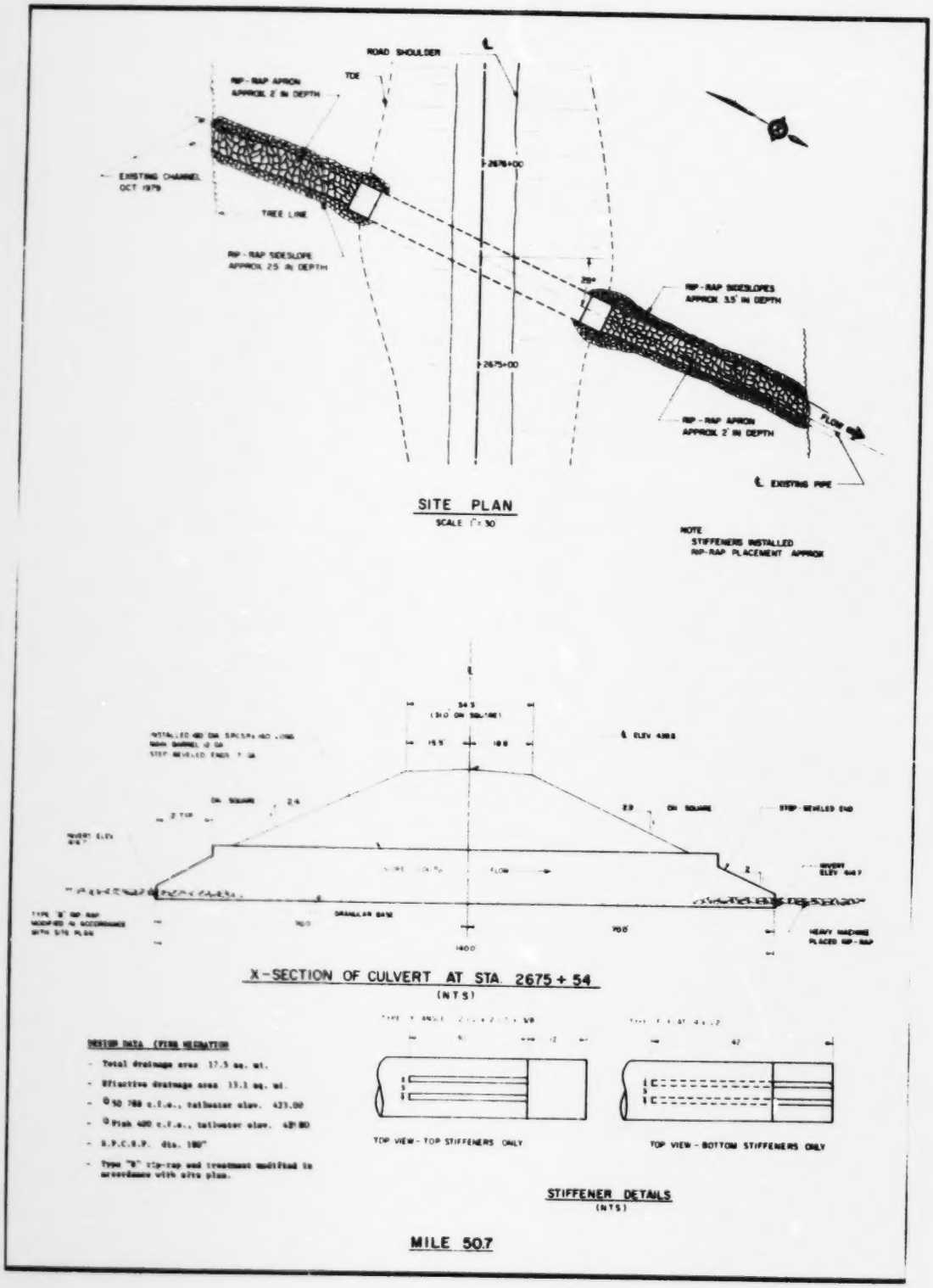

Fig. 12. Site plan of the culvert installation at Creek Mile 50.7.

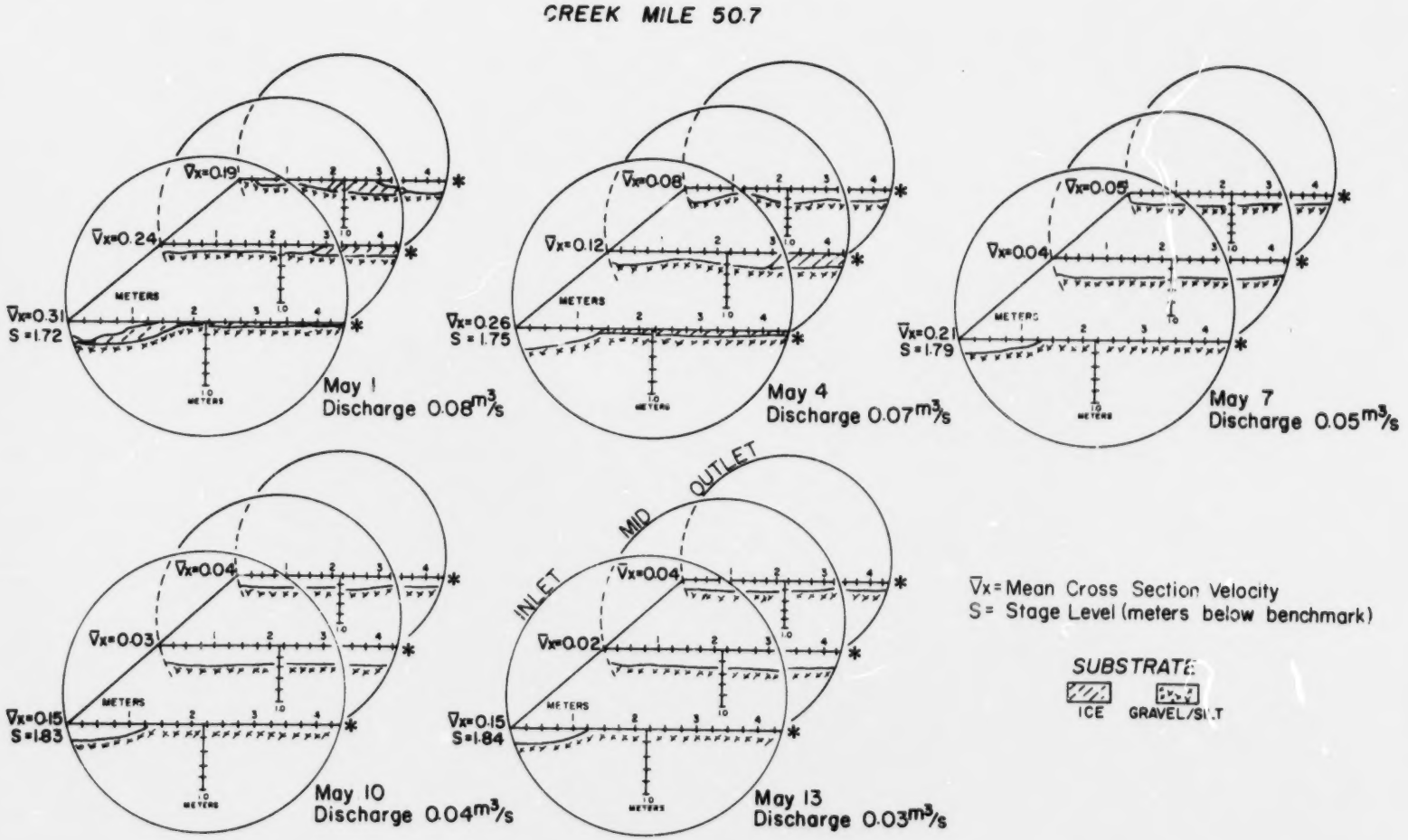

Fig. 13. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 50.7, 1980.

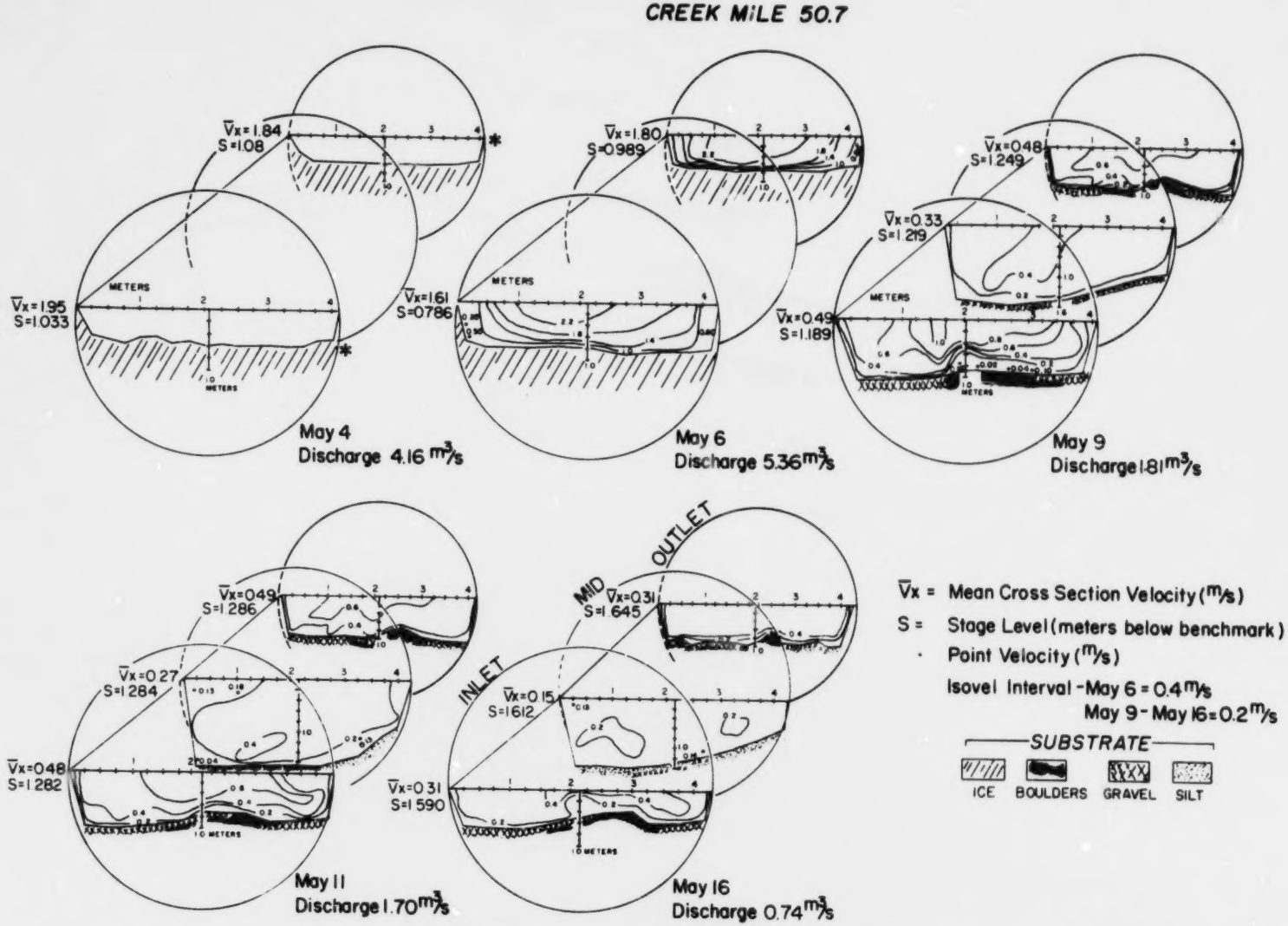

Fig. 14. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 50.7, 1981.

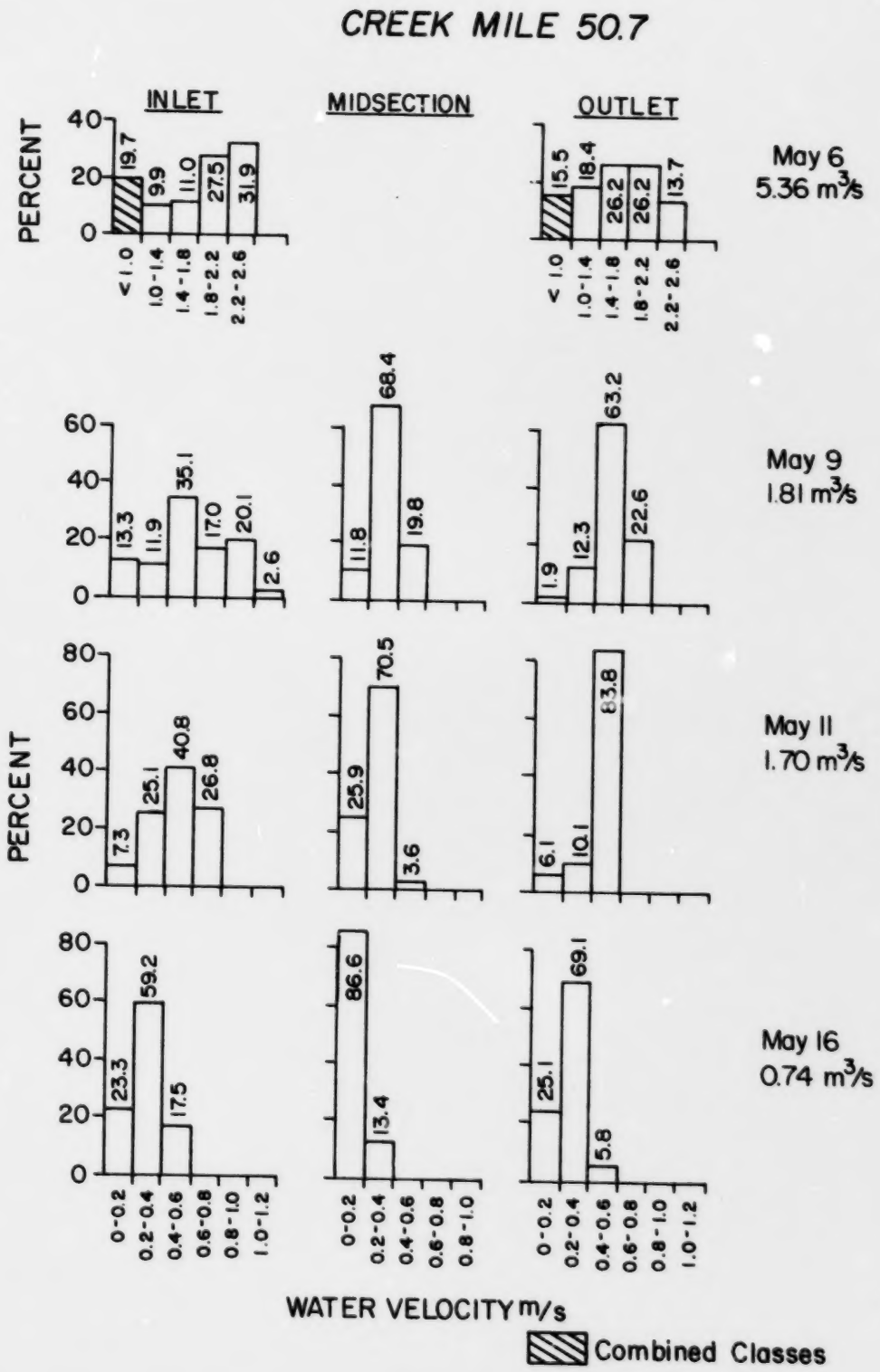

Fig. 15. Cross-sectional water velocity distribution for the culvert installation at Creek Mile 50.7, 1981.

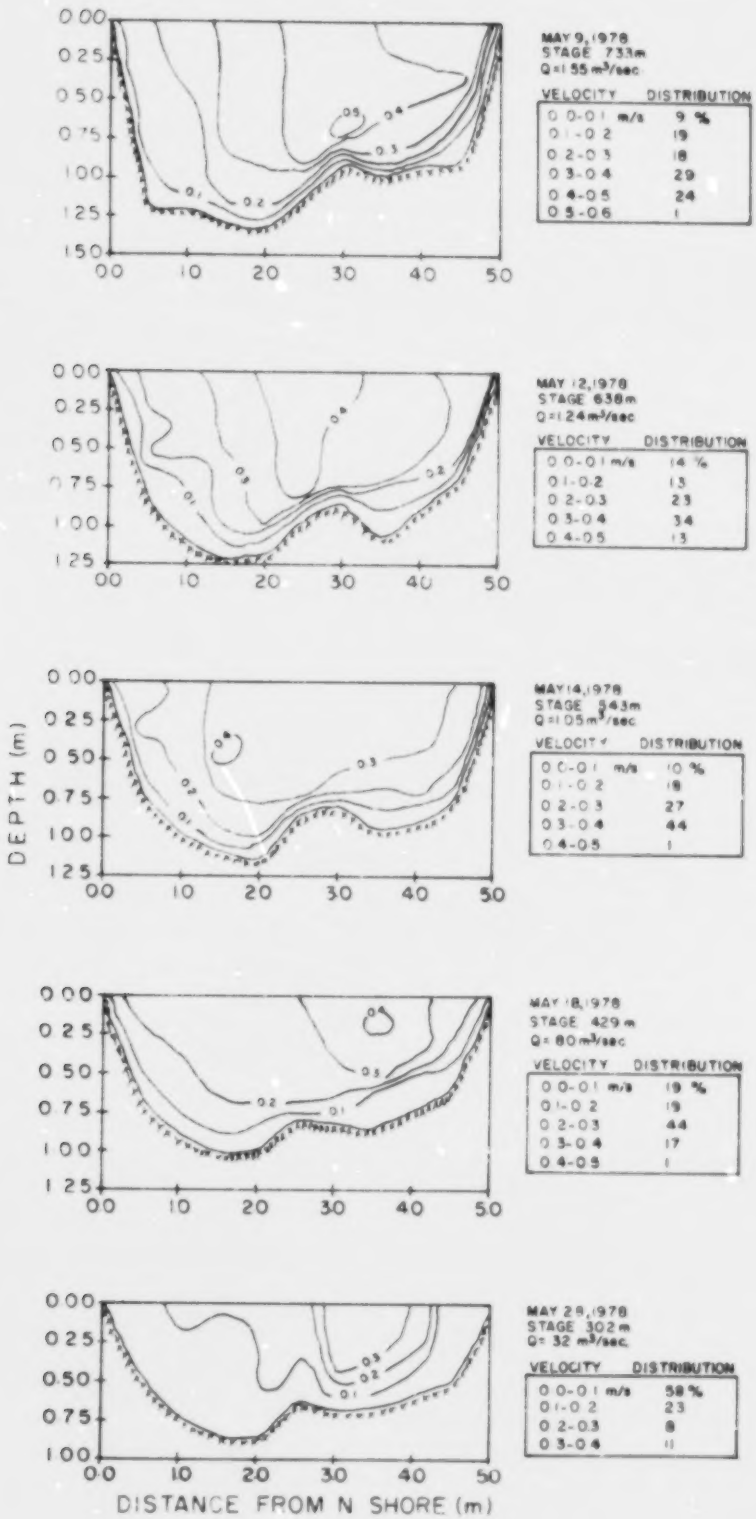

Fig. 16. Cross-sectional water velocity profiles for the natural stream channel of Creek Mile 51.9 at the highway alignment, 1978.

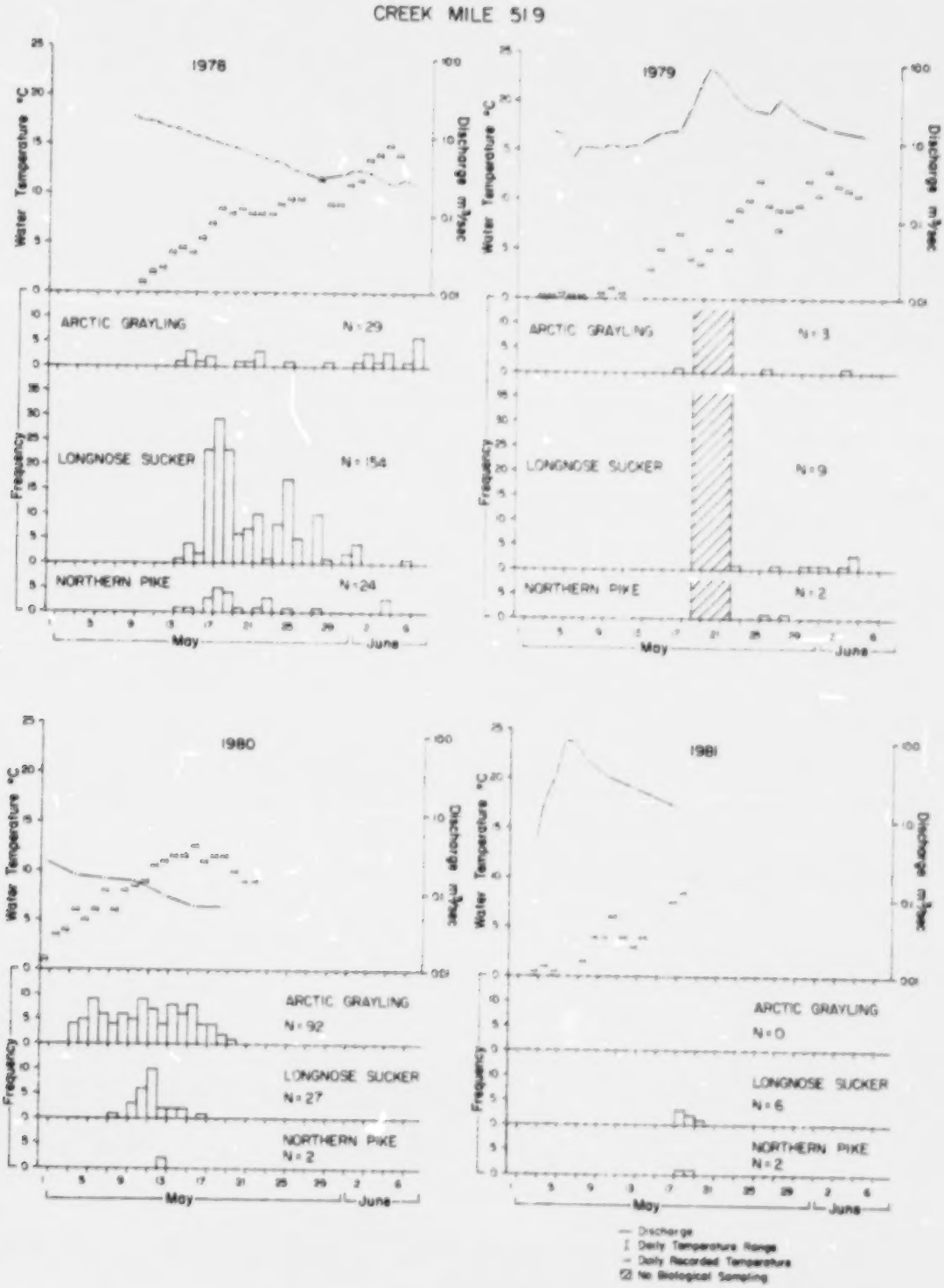

Fig. 17. Calendar catch frequency for Arctic grayling, longnose sucker and northern pike upstream migrants as compared to hydrograph and water temperature, Creek Mile 51.9, 1978-1981.

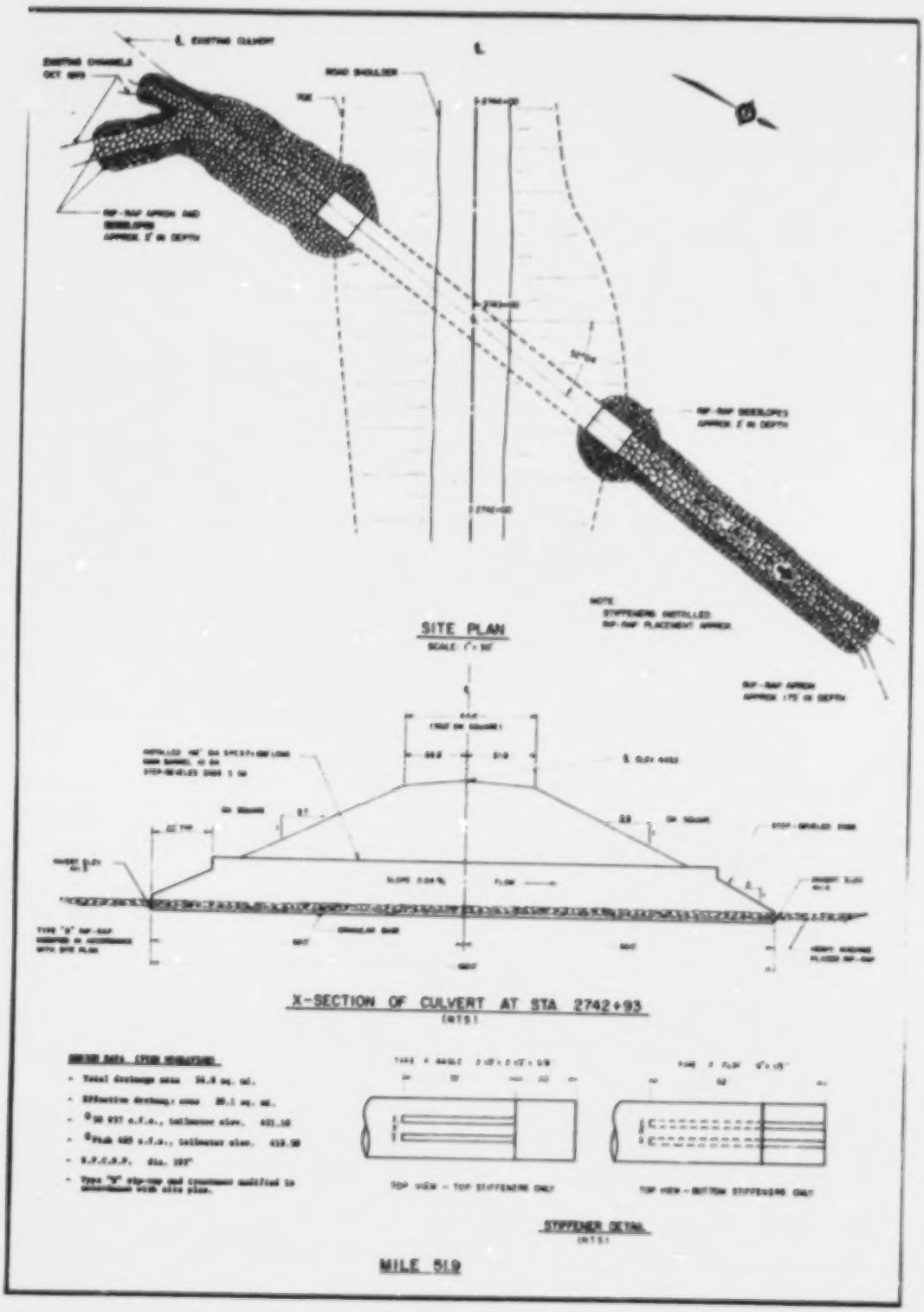

Fig. 18. Site plan of the culvert installation at Creek Mile 51.9.

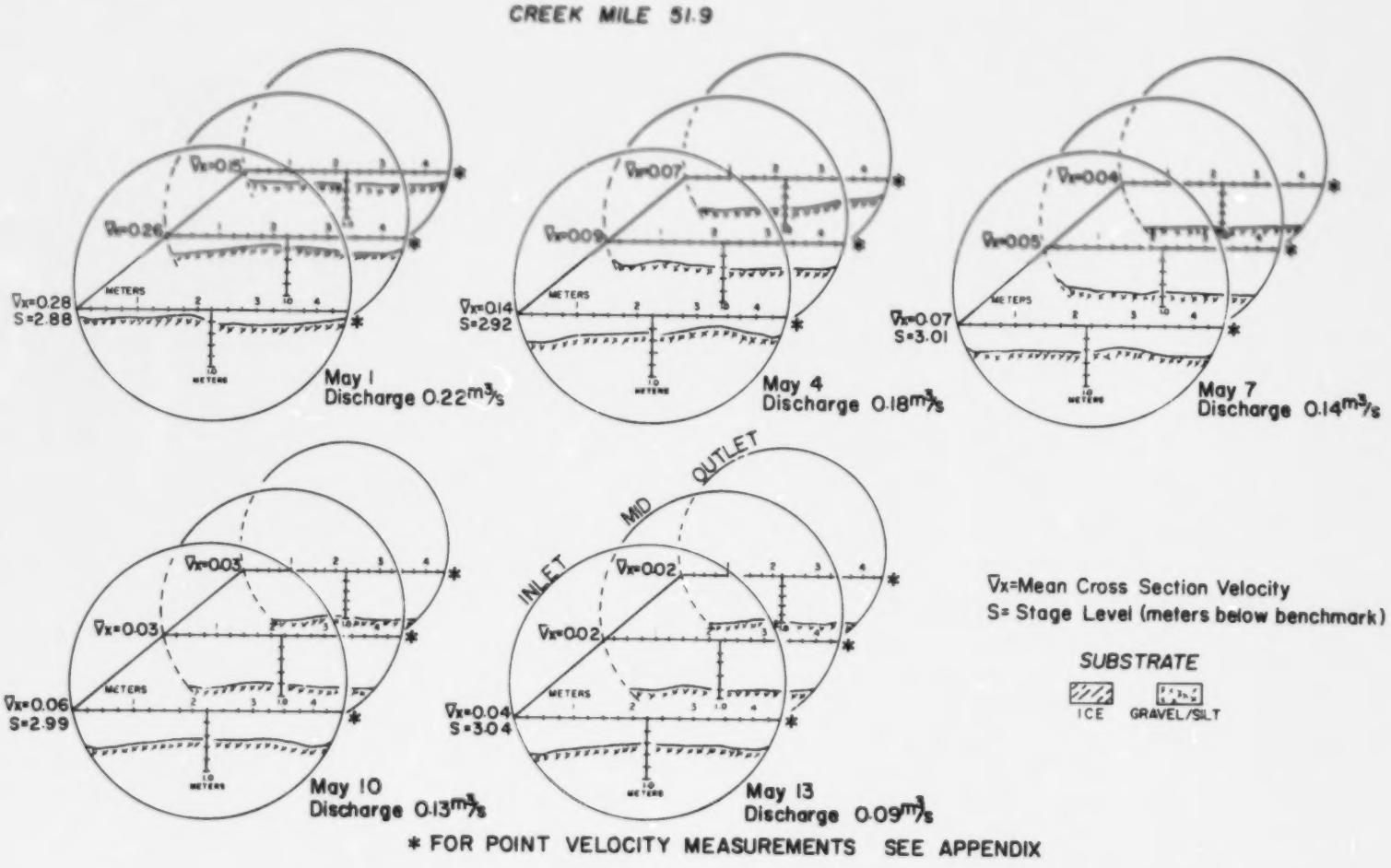

Fig. 19. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 51.9, 1980.

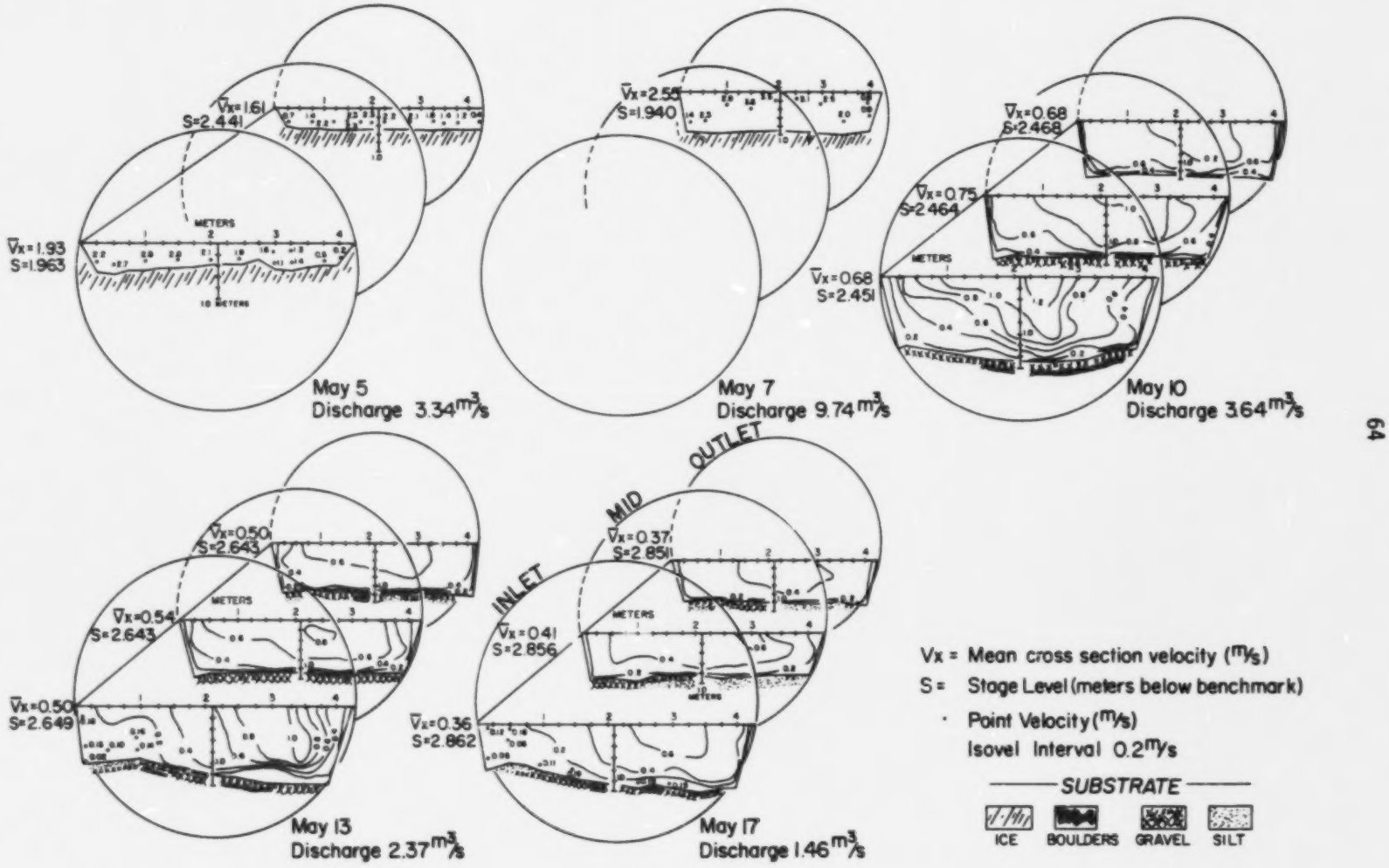

Fig. 20. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 51.9, 1981.

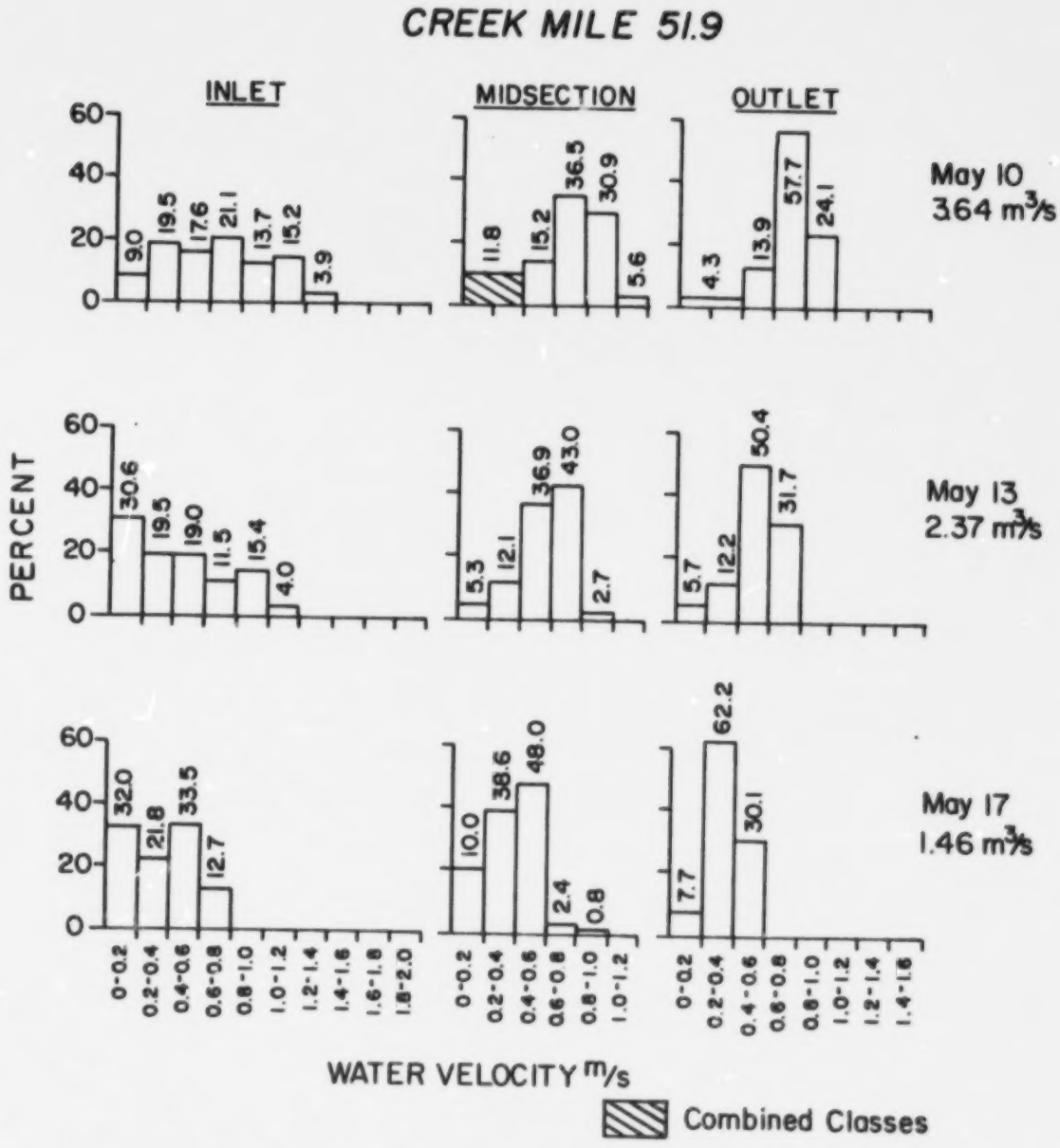

Fig. 21. Cross-sectional water velocity distribution for the culvert installation at Creek Mile 51.9, 1981.

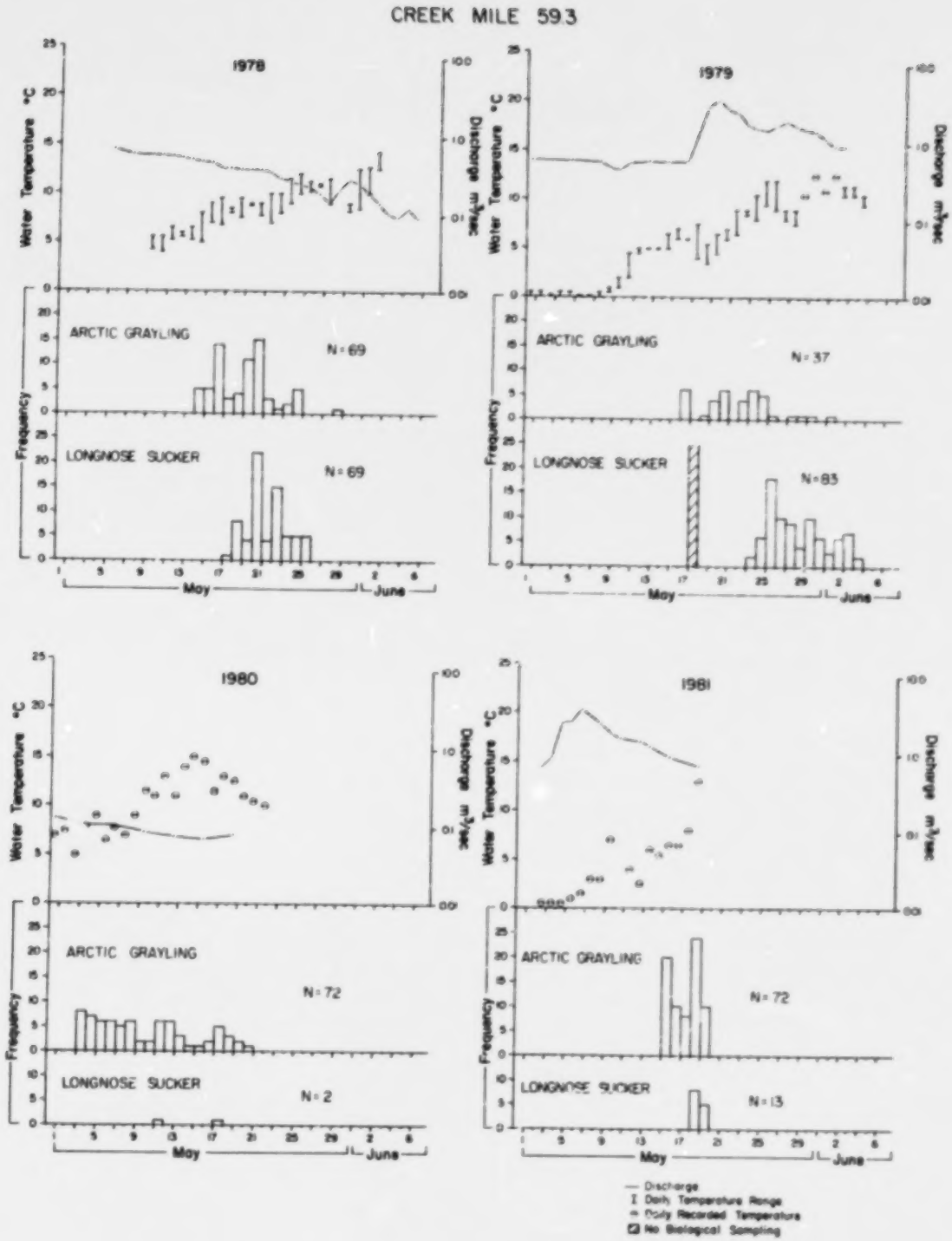

Fig. 22. Calendar catch frequency for Arctic grayling and longnose sucker upstream migrants as compared to hydrograph and water temperature, Creek Mile 59.3, 1978-1981.

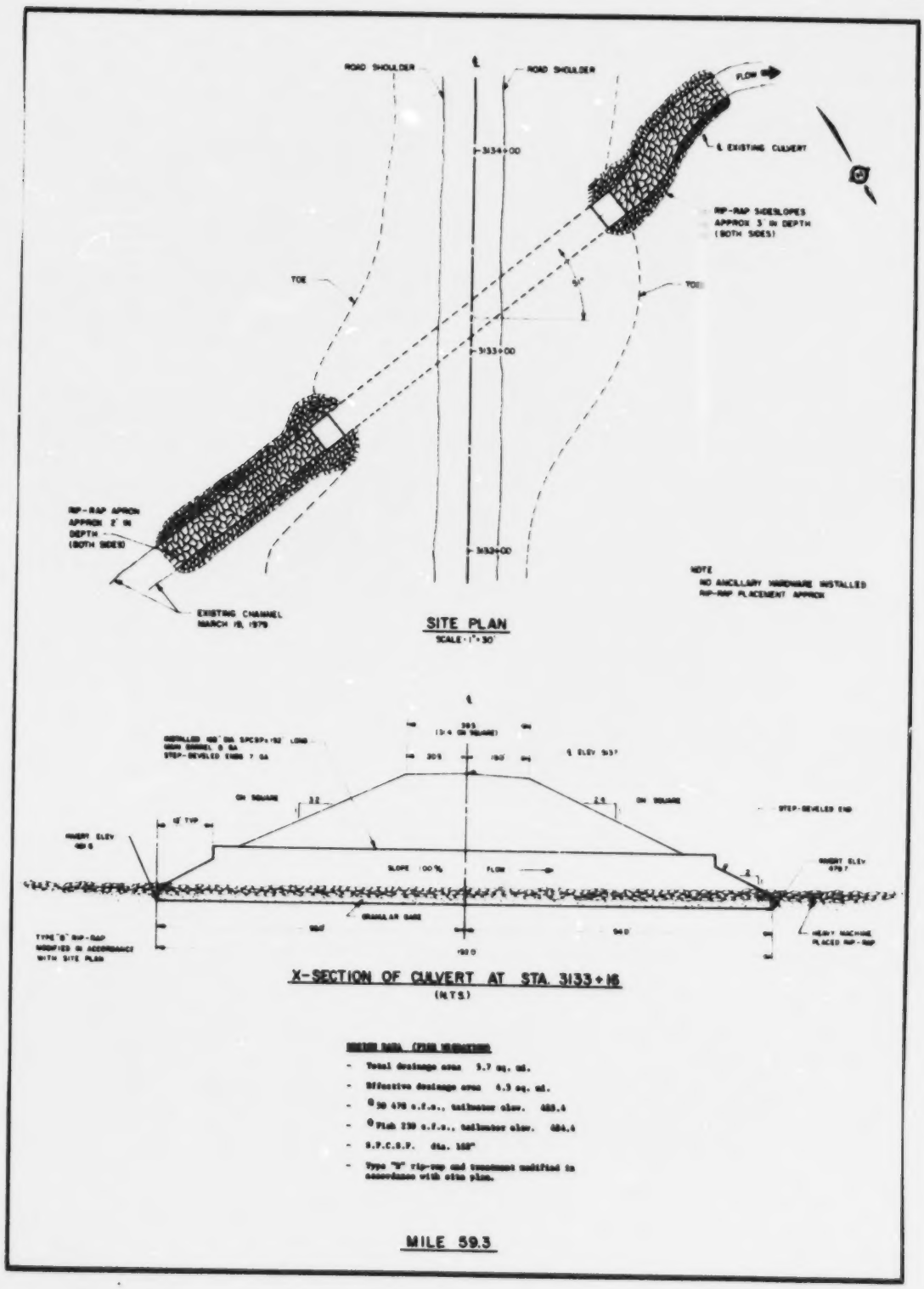

Fig. 23. Site plan of the culvert installation at Creek Mile 59.3.

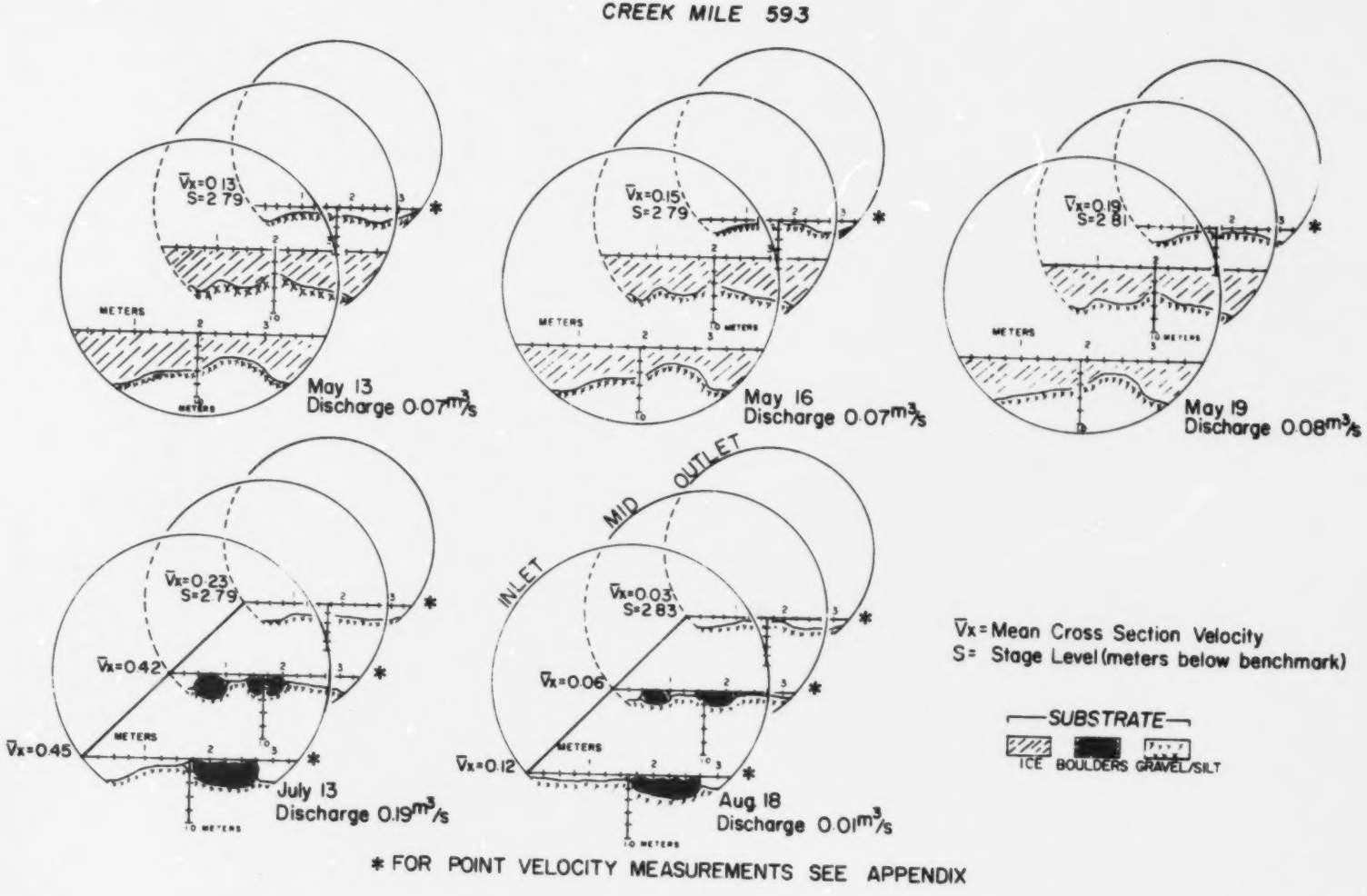

Fig. 24. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 59.3, 1980.

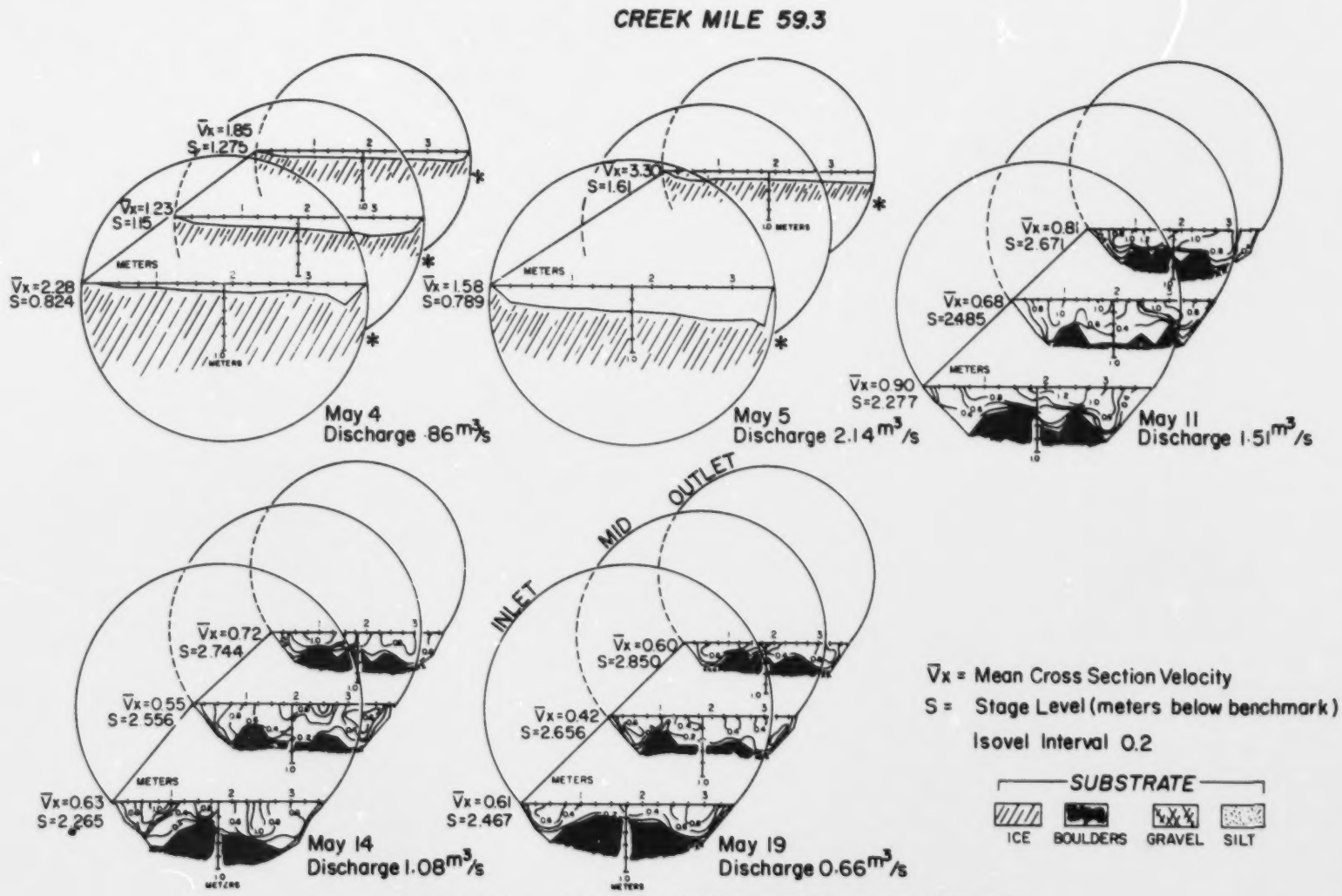

Fig. 25. Cross-sectional water velocity profiles for the culvert installation at Creek Mile 59.3, 1981.

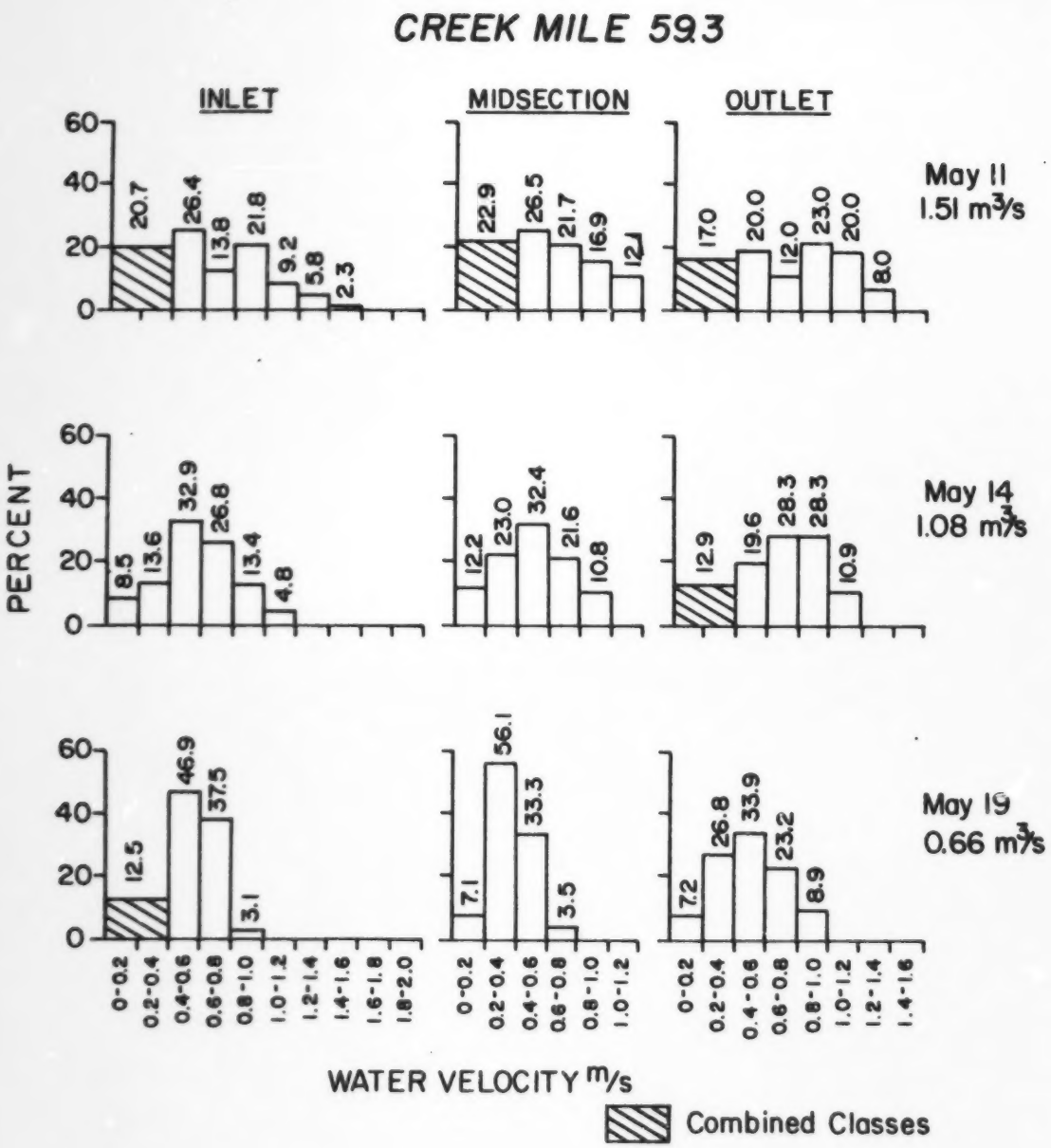

Fig. 26. Cross-sectional water velocity distribution for the culvert installation at Creek Mile 59.3, 1981.

Table A1. Alphabetical list of common names and associated generic names for fish captured.

Arctic grayling - Thymallus arcticus (Pallas)

Brook stickleback - Culaea inconstans (Kirtland)

Finescale dace - Pfrille neogaea (Cope)

Lake chub - Couesius plumbeus (Agassiz)

Longnose sucker - Catostomus catostomus (Forster)

Northern pike - Esox lucius Linnaeus

Northern redbelly dace - Chrosomus eos (Cope)

Slimy sculpin - Cottus Cognatus (Richardson)

White sucker - Catostomus commersoni (Lacépéde)

Table A2. Growth in length summary by age class for Arctic grayling from Creek Mile 48.9, 1978 - 1981.

Year	Age Class	Sampling Period	n	Mean Length (mm)	Standard Deviation	Range (mm)
1978	1	IV	2	187.5	0.7	187-188
	2	IV	1	217.0	-	-
1979	2	I	3	182.7	3.1	180-186
	2	III	3	195.0	4.0	191-199
1980	No aged samples from 1980.					
1981	3	I	1	236.0	-	-
	5	I	1	283.0	-	-

SAMPLING PERIOD INDEX

Sample Period	Study Year	1978	1979	1980	1981
I		May 14-June 9	May 17-June 4	May 4-23	May 15-20
II		N/A	July 10-11	July 13-14	N/A
III		N/A	August 19-20	August 17-18	N/A
IV		Sept. 20-24	Sept. 8-10	Sept. 16-18	N/A

Table A3. Individual fish data from Creek Mile 48.9 Liard Highway Study 1978 to 1981.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Arctic grayling	23/09	187	90.	M2	2	
		188	90.	F1	1	
		217	140.	F2	2	
Longnose sucker	23/09	152	31.2	-	-	
Brook stickleback	23/05	69	2.1	F2	4	
		62	1.8	F3	-	
	30/05	60	1.6	F1	3	
	05/06	62	2.2	F3	3	
	07/06	66	2.7	F3	3	
		62	1.9	-	3	
		43	0.3	-	-	
	08/06	65	2.5	F3	-	
		62	2.2	F3	-	
		42	0.6	F3	-	
		48	-	-	2	
	09/06	41	0.6	F1	2	
Finescale dace	29/05	71	3.7	F3	4	
		52	1.1	F2	3	
		44	0.5	M2	2	
	30/05	66	2.9	F3	5	
		49	0.9	F1	3	
	02/06	48	0.6	-	-	
	04/06	64	2.7	M3	-	
	06/06	69	3.4	M3	3	
		81	5.2	F3	4	
		55	1.5	F2	5	
		50	1.1	M2	3	
		48	0.9	F1	3	
		45	0.8	F3	-	
	07/06	44	0.5	F1	3	
		49	0.5	-	3	
	08/06	61	2.3	F3	5	
		58	1.9	F3	3	
		55	1.5	M2	4	
	09/06	62	2.7	F3	4	
	1979					
Arctic grayling	25/05	180	50.	M1	2	
	28/05	186	-	F1	2	
	01/06	182	-	-	2	
	20/08	191	75.	M2	2	
		195	88.	M2	2	
		199	80.	F2	2	
Longnose sucker	04/06	328	400.	F3		
	20/08	39	0.5	0	0	
		40	0.4	0	0	
		37	0.3	0	0	
		36	0.3	0	0	
		38	0.4	0	0	
		45	0.8	0	0	
		38	0.4	0	0	
		43	0.7	0	0	
		43	0.7	0	0	
		41	0.5	0	0	
		41	0.5	0	0	
Longnose sucker	08-09	42	0.7	0	0	
		43	0.6	0	0	
		44	0.9	0	0	
		46	1.1	0	0	
	09-09	43	0.7	0	0	
		42	0.5	0	0	
		47	0.8	0	0	
		43	0.6	0	0	
	10/09	46	0.9	0	0	
		45	0.8	0	0	
		52	1.2	0	0	
		44	0.7	0	0	
Brook stickleback	01/05	49	0.6	F2	-	
	20/08	22	0.1	-	0	
		29	0.2	-	0	
		36	0.3	-	0	
Lake chub	10/09	29	0.2	-	-	
	1980					
Arctic grayling	12/05	190	66.	M3	-	
	19/05	155	41.	F1	-	
Brook stickleback	14/07	14(1)	-	0	0	
		15(2)	-	0	0	
		16(2)	-	0	0	
		17(2)	-	0	0	
		19(1)	-	0	0	
		20(1)	-	0	0	
	18/08	17(1)	<0.1	0		
		18(1)	<0.1	0		
		22(2)	0.1	0		
		23(4)	0.1	0		
		24(1)	0.1	0		
		25(1)	0.1	0		
		26(2)	0.1			
		27(1)	0.2			
		31(1)	0.2	-	-	
		35(1)	0.4	-	-	
Lake chub	21/05	90	8.8	F2	2	
	1981					
Arctic grayling	15/05	236	-	M3	3	
	20/05	283	247.	M4	5	R/C-29469
Brook stickleback	20/05	58	1.4	-	-	
		57	1.1	-	-	

Table A4. In-Culvert Velocity Measurements, Creek Mile 48.9 Liard Highway Study, 1980.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity
May 1	Inlet	0.05m	23cm	7 cm	43cm/s	May 6	*Mid	0.05m	33cm	13cm	7cm/s	May 7	Outlet	0.15m	26cm	7cm	7 cm/s
				10	60			0.50	22	7	6					11	11
				17	60					9	7					16	14
		0.25	23	7	72					13	5			0.50	28	11	10
				10	42					18	5					22	14
				14	104			1.0	12	7	n/c			0.75	26	7	9
				17	106			1.5	10	7	n/c					11	9
		0.50	17	7	52			2.0	11	7	n/c					16	9
				10	52			2.5	14	7	1					21	10
				14	47			3.0	10	7	n/c			1.25	26	7	9
		0.75	15	7	44			3.5	17	7	18					11	9
				9	48					10	15					16	9
				12	50					14	15					21	10
		1.0	10		46			4.0	17	7	32			1.5	25	10	7
		1.24	7	-	n/c					11	37					15	6
		1.5	6	-	n/c					14	38					20	8
		1.75	3	-	n/c			4.25	18	7	33			2.0	33	10	5
		2.0	0	-	-			4.5	18	7	19			2.25	26	10	2
	*Mid	0.25	37	7	44					11	25					21	3
				15	46			4.75	0	14	25			2.5	Ice Edge		n/c
				29	45					-	-						
		0.5	25	7	42		Outlet	0.25	31	14	16	May 10	Inlet	0.1	8	7	21
				10	47			0.5	31	7	10			0.25	8	7	28
				20	40					12	16			0.75	10	7	62
		0.75	20	7	42					19	14			0.85	11	7	64
				10	36					25	17			1.0	11	7	72
				16	30			1.0	30	12	11			1.1	7	7	31
		1.0	15	7	19			1.5	28	7	6		*Mid	0.25	24	10	4
		1.25	12	7	3					11	8			0.75	11	- n/m	-
		1.5	14	7	n/c					17	9			1.25	7	- n/m	-
		1.75	15	7	n/c					22	11			1.75	6	- n/m	-
		1.8	0	-	-			2.0	29	11	5			2.25	11	- n/m	-
								2.5	0	Ice Edge				2.75	6	- n/m	-
	Outlet	0.1	35	7	7									3.25	10	- n/m	-
				14	9	May 7	Inlet	0.1	8	7	40						
				21	10			0.25	8	7	46		Outlet	0.25	24	10	11
				28	9			0.5	12	7	68			0.75	24	7	7
		0.25	35	7	7			0.75	12	7	65					10	8
				14	9			0.9	8	7	47					14	8
				21	10			1.0	3	7	-					19	9
				28	12			1.2	0	-	-			1.25	21	8	5
		0.5	35	7	11									1.75	16	7	3
				14	14		*Mid	0.25	28	11	7			2.25	24	10	1
				21	15			0.5	19	4	2			2.75	29	11	n/c
				28	15			0.75	12	7	1			3.25	30	12	1
		0.65	0	-	-			1.0	8	7	n/c			3.75	30	12	n/c
								1.25	8	7	n/c			4.25	30	12	n/c
May 4	Inlet	0.1	15	7	61			1.5	6	-	n/c			4.5	30	12	n/c
		0.25	26	7	66			1.75	8	-	n/c			4.75	0	-	-
				13	79			2.0	9	-	n/c						
		0.5	17	7	56			2.25	15	-	n/c			After May 10, Cross Sectional Depths Only.			
				14	80			2.5	8	-	n/c						
		0.75	15	7	51			2.75	8	-	n/c						
				12	57			3.0	10	-	n/c						
		1.0	8	7	51												
		1.25	5	-	n/c												
		1.5	0	-	-												

[1]NOTE: All measurements start at South side, except where noted (*).

n/c No Current
n/m No Measurement

Table A5. In-Culvert Velocity Measurements, Creek Mile 48.9 Liard Highway Study 1981.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
[1]May 3	Inlet	0.25 m	7 cm	6 cm	17 cm/s
		0.50	8	6	38
		0.75	8	6	38
		1.0	10	6	55
		1.25	10	6	80
		1.5	10	6	97
		1.75	10	6	100
		2.0	10	6	95
		2.25	10	6	75
		2.5	9	6	53
		2.75	8	6	40
		3.0	7	6	32
		3.25	7	6	27
		3.5	7	6	21
		3.75	7	6	22
		4.0	6	6	B/E
		4.25	6	6	B/E
		4.5	5	3	B/E
		4.7	0	-	-
	Mid	0.15	7	4	39
		0.25	7	5	59
		0.5	12	6	62
				10	73
		0.75	11	6	65
				10	58
		1.0	6	6	56
		1.25	7	6	50
		1.5	7	6	51
		1.75	7	6	50
		2.0	7	6	58
		2.25	7	5	54
		2.5	7	6	57
		2.75	7	6	52
		3.0	7	6	43
		3.25	7	6	46
		3.5	7	6	47
		3.75	8	6	42
		4.0	8	6	47
		4.25	8	6	49
		4.5	6	5	50
		4.75	0	-	-
	Outlet	0.15	7	6	B/E
		0.25	8	6	20
		0.5	10	6	61
		0.75	11	6	61
				10	75
		1.0	10	6	67
		1.25	10	6	58
				9	65
		1.5 m	10 cm	6 cm	51 cm/s
		1.75	10	6	61
		2.0	10	6	58
		2.25	9	6	58
		2.5	9	6	52
		2.75	9	6	55
		3.0	9	6	55
		3.25	8	6	56
		3.5	8	6	45
		3.75	8	6	14
		4.0	7	6	B/E
		4.25	7	6	B/E
		4.5	7	6	B/E
		4.75	0	-	-
May 3	D/S	0.25	5	5	6
		0.5	9	6	81
		0.75	12	6	98
		1.0	13	6	92
		1.25	14	6	127
		1.5	13	10	121
		1.75	12	6	125
		2.0	7	6	117
		2.15	5	3	73
		2.25	0	-	-
[1]May 4	Inlet	0.15	17	6	30
		0.25	17	6	30
		0.5	20	8	47
		0.75	23	9	101
		1.0	25	10	131
		1.25	26	10	155
		1.5	32	13	158
		2.0	35	13	162
		2.5	26	11	164
		3.0	21	8	47
		3.5	16	6	32
		4.0	15	6	14
		4.5	13	6	6
		4.75	0	-	-
	Outlet	0.25	19	8	103
		0.5	20	8	128
		0.75	20	8	124
		1.0	21	8	118
		1.25	22	8	112
		1.75	23	9	109
		2.25	22	9	120
		2.75	22	9	117
		3.25	22	9	103
		3.75	22	9	117
		4.25	22	9	114
		4.5 m	20 cm	9 cm	87 cm/s
		4.65	10	6	48
		4.75	0	-	-
[1]May 5	Outlet	0.15	20	8	80
		0.25	25	10	90
		0.5	28	11	128
				22	142
		0.75	29	12	138
		1.0	33	13	128
				26	153
		1.25	31	12	138
		1.5	32	12	137
				26	148
		1.75	32	12	124
		2.0	32	12	132
				26	168
		2.25	33	12	131
		2.5	36	12	139
				20	182
		2.75	33	12	124
		3.0	33	12	126
				20	115
		3.25	32	12	119
		3.5	31	12	125
				25	135
May 6	Inlet	0.15	25	10	111
		0.25	28	11	105
		0.5	38	15	127
		1.0	43	17	149
		1.5	47	19	194
		2.0	50	20	170
				40	178
		2.5	47	19	141
		3.0	42	17	135
		4.0	21	8	85
		4.5	18	8	46
		4.75	0	-	-
	Outlet	0.15	44	16	53
		0.25	48	19	63
		0.5	53	20	83
		1.0	56	21	112
		1.5	56	21	104
				42	115
		2.0	59	10	89
				24	114
		2.5	60	10	105
				24	110
				48	132
		3.0	58	27	113

Table A5. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 6	Outlet cont'd	3.5 m	55 cm	22 cm	95 cm/s
				44	94
		4.0	54	22	72
		4.5	45	18	54
		4.7	35	14	38
		4.75	0	-	-
[1]May 7	Inlet	0.25	45	18	108
		0.75	68	14	97
				27	123
				54	129
		1.0	63		n/m
		1.25	64	13	93
		1.5	70		n/m
		1.75	78	15	53
				31	112
				47	115
				62	150
		2.0	74		n/m
		2.25	77	15	107
				31	126
				46	141
				62	137
		2.5	69		n/m
		2.75	74	15	72
				30	66
				59	103
		3.0	60		n/m
		3.25	59	12	81
				24	82
				48	84
		3.5	54		n/m
		3.75	43	17	78
		4.0	36		n/m
		4.25	34	14	52
		4.5	32		n/m
		4.7	30	12	43
		4.75	0	-	-
	Outlet	0.15	50	20	48
		0.25	61	25	64
		0.75	66	25	78
		1.25	66	13	64
				25	87
				40	94
				53	105
		1.75	55	22	99
		2.25	67	12	71
				24	106
				36	99
				48	114
		2.75 m	58 cm	23 cm	100 cm/s
		3.25	62	12	74
				25	97
				37	101
				50	98
		3.75	65	26	85
		4.25	56	11	78
				22	78
				34	83
				45	81
		4.7	45	9	53
				18	65
				36	69
		4.75	0	-	-
[1]May 8	Inlet	0.15	53	10	60
				40	61
		0.5	70	14	83
				28	87
		1.0	82	16	67
				32	83
				65	111
		1.25	90		n/m
		1.5	90	10	24
				18	86
				36	98
				54	98
				72	133
		1.75	90		n/m
		2.0	95	10	B/E
				20	40
				40	61
				60	172
				80	186
		2.25	85		n/m
		2.5	65	10	38
				25	58
				50	77
		2.75	72		n/m
		3.0	68	14	46
				28	42
				56	80
		3.0	83	10	14
				25	48
		3.25	75		n/m
		3.5	75	15	44
				30	57
				60	72
		3.75	54		n/m
		4.0	47	9	35
				18	47
				36	53
		4.25	41		n/m
		4.5 m	40 cm	16 cm	18 cm/s
		4.75	-	-	-
	Mid	0.15	53	11	46
				22	62
				41	37
		0.5	65	13	58
				26	83
				52	76
		1.0	65	13	71
				26	79
				52	81
		1.5	65	26	77
		2.0	70	14	74
				28	81
				42	81
				56	88
		2.5	71	28	67
		3.0	65	13	59
				26	62
				52	83
		3.5	55	22	59
		4.0	60	12	38
				24	44
				48	51
		4.5	55	11	43
				22	56
				49	44
		4.75	0	-	-
	Outlet	0.15	50	10	47
				20	37
				40	56
		0.5	56	22	69
				44	78
		1.0	59	12	70
				24	84
				35	87
				47	75
		1.5	57	11	63
				23	71
				46	89
		2.0	56	11	53
				22	76
				34	81
				45	88
		2.5	58	12	59
				23	79
				46	85
		3.0	55	11	53

Table A6. Cont'd.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 8 cont'd	Outlet			22	73
				33	80
				44	82
		3.5 m	56 cm	11 cm	58 cm/s
				22	70
				33	80
				44	81
		4.0	61	12	63
				44	82
				36	72
				48	69
		4.5	50	10	56
				20	57
				40	72
		4.65	48	10	44
				20	47
		4.75	0	-	-
[1]May 9	Outlet	0.15	50	20	49
		0.5	53	21	57
		1.0	55	22	56
		1.5	52	20	55
		2.0	65	26	56
		2.5	80	32	54
		3.0	80	32	53
		3.5	72	29	51
		4.0	72	29	59
		4.5	70	28	42
		4.65	70	29	20
		4.75	0	-	-
May 14	Inlet	0.15	55	10	36
				20	55
			40	49	
		0.5	61	10	52
				20	70
				40	60
				55	55
		1.0	60	10	32
				20	39
				40	46
				55	48
		1.5	55	10	B/E
				20	22
				40	52
		2.0 m	60 cm	10 cm	2 cm/s
				20	20
				40	48
		2.5	37	10	14
				20	6
				30	4
		3.0	34	10	2
				30	B/E
		3.5	47	10	0
				30	B/E
		4.0	50	10	20
				20	26
				40	23
		4.5	50	10	29
				20	37
				40	39
		4.8	0	-	-
	Mid	-0.05			
		0.15	55	10	39
				20	39
				40	37
		0.5	65	10	42
				20	48
				40	52
		1.0	55	10	37
				20	40
				40	45
				52	44
		1.75	55	10	11
				20	23
				40	38
				52	42
		2.5	55	10	17
				20	23
				40	30
		3.25	42	10	25
				20	29
				40	33
		4.0	47	10	24
				20	29
				40	32
		4.6 m	50 cm	10 cm	20 cm/s
				20	25
				40	27
		4.75	0	-	-
	Outlet	0.15	44	10	24
				20	29
				35	30
		0.5	45	10	32
				20	41
				30	77
		1.0	50	10	16
		1.5	56	10	9
				20	29
				30	38
				50	45
		2.0	56	10	4
				20	27
				20	36
				40	50
				45	36
		2.5	72	10	B/E
				20	12
				40	33
				60	35
		3.0	90	10	B/E
				20	6
				40	19
				60	26
				80	33
		3.5	90	10	B/E
				20	3
				40	20
				60	32
				80	36
		4.0	80	10	9
				20	11
				40	31
				65	38
		4.5	68	10	19
				20	32
				40	30
				60	29
		4.8	0	-	-

[1]Note: All measurements on ice.
n/c no current
n/m no measurement
B/E back eddy
*All shore measurements start at 0.00 m except where indicated.

Table A6. Growth in length summary by age class for Arctic grayling from Creek Mile 50.7, 1978 - 1981.

Year	Age Class	Sampling Period	n	Mean Length (mm)	Standard Deviation	Range (mm)
1978	0	IV	1	63.0	-	-
	1	I	48	80.0	9.2	65-105
	1	IV	5	128.6	11.0	115-140
	2	I	2	213.0	0.0	-
	2	IV	5	192.0	17.9	175-217
	3	I	16	227.7	16.6	199-258
	4	I	17	261.1	26.0	214-297
	5	I	4	261.8	7.6	254-272
1979	0	IV	1	64.0	-	-
	1	IV	1	133.0	-	-
	2	III	3	176.3	3.8	172-179
	2	IV	4	175.8	6.7	167-183
	3	I	3	235.7	15.2	222-252
	4	I	4	253.5	17.6	230-272
	5	I	2	321.0	1.4	320-322
	6	I	1	340.0	-	-
1980	2	I	3	156.3	36.9	115-186
	2	IV	1	203.0	-	-
	3	I	33	191.7	14.4	166-225
	3	II	1	215.0	-	-
	3	IV	2	222.0	4.2	219-225
	5	I	2	278.0	22.6	262-294
	5	IV	2	285.0	19.8	271-299
1981	3	I	6	183.7	15.3	163-203
	4	I	3	252.3	41.7	207-289

SAMPLING PERIOD INDEX

Sample Period	Study Year 1978	1979	1980	1981
I	May 14-June 9	May 17-June 4	May 4-23	May 15-20
II	N/A	July 10-11	July 13-14	N/A
III	N/A	August 19-20	August 17-18	N/A
IV	Sept 20-24	Sept 8-10	Sept 16-18	N/A

Table A7. Individual fish data from Creek Mile 50.7 Liard Highway Study 1978-1981.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Arctic grayling	19/05	232	120.	M2	3	
		231	100.	F5	4	
		240	110.	M3	4	
		199	80.	F3	3	
		263	160.	M4	4	
		258	150.	M4	3	
	20/05	282	200.	F5	4	
	23/05	274	210.	M5	4	
		254	170.	F5	5	
		236	110.	F5	3	
	25/05	297	280.	M5	4	
	29/05	262	200.	M5	4	
		272	200.	-	4	Tag-29351
	30/05	219	100.	F5	3	
		213	100.	-	2	
		294	260.	-	4	Tag-29352
	31/05	285	250.	M5	4	
		95	7.1	M1	1	
		82	4.6	F1	1	
		85	4.6	F1	1	
		102	8.8	M1	1	
		79	4.1	-	1	
		82	4.2	F1	1	
		90	6.2	M1	1	
		88	5.6	M1	1	
		77	4.0	F1	1	
		89	5.5	F1	1	
		83	4.8	F1	1	
		78	4.1	F1	1	
		105	7.3	M1	1	
		81	4.5	M1	1	
		84	4.8	-	1	
		72	3.2	-	1	
		87	5.0	-	1	
		80	4.2	-	1	
		67	2.5	-	1	
		72	3.1	F1	1	
		85	5.4	F1	1	
		91	6.2	F1	1	
		90	5.8	F1	1	
		81	4.9	-	1	
		76	3.6	-	1	
		82	4.9	-	1	
		67	2.8	-	1	
		93	6.0	-	1	
		84	4.6	-	1	
		66	2.6	-	1	
		69	3.0	-	1	
		86	4.8	-	1	
		75	3.7	M1	1	
		70	2.7	-	1	
		79	3.4	M1	1	
		70	2.6	-	1	
		79	3.7	-	1	
		71	3.0	-	1	
		65	2.1	-	1	
		74	3.3	-	1	
		68	2.5	-	1	
		73	3.3	-	1	
		72	2.9	-	1	
		87	5.1	-	1	
Arctic grayling	31/05	86	5.0	-	1	
		73	3.1	-	1	
		81	4.4	-	1	
		71	2.7	-	1	
	02/06	297	280.	M5	4	
	03/06	252	190.	-	4	Tag-29360
		217	120.	-	3	Tag-29361
	04/06	259	190.	M5	5	
		254	180.	F5	4	
		215	120.	F5	3	
		262	210.	M5	5	
	05/06	224	130.	-	3	Tag-29363
	06/06	247	160.	M5	3	
		249	170.	F5	4	
		228	140.	M5	3	
		218	120.	F5	3	
		215	120.	M5	3	
		217	120.	M5	4	
		244	160.	M5	3	
		225	140.	M5	3	
		214	110.	F5	4	
		255	180.	-	3	Tag-29364
	07/06	256	200.	-	4	Tag-29365
		213	110.	-	2	Tag-29366
		211	110.	-	3	Tag-29367
	08/06	272	230.	-	5	Tag-29368
	21/09	204	78.	M1	2	
		179	52.	F1	2	
		175	46.	-	2	
		185	56.	M2	2	
		138	22.9	M1	1	
		140	22.3	M1	1	
		130	18.0	M1	1	
		120	14.3	F1	1	
		115	11.6	M1	1	
		63	1.9	0	0	
	24/09	217	100.	F2	2	
Longnose sucker	31/05	313	360.	M4	-	
	03/06	41(1)	0.6	0	1	
		29(1)	0.2	0	1	
		31(2)	0.2	0	1	
		32(2)	0.2	0	1	
		33(1)	0.2	0	1	
		34(2)	0.3	0	1	
		35(3)	0.3	0	1	
		36(1)	0.4	0	-	
		38(1)	0.5	0	-	
	08/06	31(3)	0.3	0	1	
		32(3)	0.3	0	1	
		33(7)	0.3	0	1	
		34(7)	0.3	0	1	
		35(3)	0.4	0	1	
		37(1)	0.5	0	1	
		38(1)	0.5	0	1	
White sucker	31/05	247	170.	M1		
Brook stickleback	03/06	56	2.0	F3	3	
	08/06	65	1.9	F3	-	
		51	1.3	F3	3	
		50	1.2	F3	-	
		49	1.0	F3	3	
		35	0.4	F2	1	
		34	0.3	M2	1	

Table A7. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Lake chub	31/05	67	3.2	F3	3	
Slimy sculpin	24/09	40	0.3	-	1	
	1979					
Arctic grayling	17/05	272	200.	M4	4	Tag-29369
		253	140.	M4	4	
		322	326.	M4	5	Tag-29376
		233	116.	M4	3	
		320	330.	M4	5	Tag-29371
	18/05	259	170.	-	4	Tag-29373
		230	140.	-	4	
		252	170.	M4	3	Tag-29374
		222	110.	-	3	
	23/05	340	450.	M4	6	Tag-29388
	19/08	178	62.	F2	2	
		179	55.	F1	2	
		172	52.	F1	2	
	08/09	178	56.	F2	2	
		64	2.0	0	0	
		133	22.	M1	1	
	09/09	167	48.	F2	2	
		175	60.	F2	2	
		183	60.	F1	2	
Longnose sucker	22/05	310	-	M4	-	
		342	430.	M4		Tag-29384
		341	490.	F3		Tag-29385
	23/05	316	380.	M4		
		305	330.	M4		
		345	480.	F3		Tag-29390
	25/05	369	500.	F3		Tag-29401
		340	460.	F3		Tag-29402
		348	476.	F3		
	26/05	341	430.	F3		
	31/05	302	300.	M4		Tag-29428
		340	410.	M4		Tag-29429
		365	470.	F3		Tag-29430
		365	530.	F4		Tag-29431
		365	530.	F4		Tag-29432
	01/06	344	420.	M4		Tag-29438
	02/06	339	430.	M4		
	20/08	40	0.5	-		
		40	0.6	-		
	10/09	45	0.8	-		
	1980					
Arctic grayling	10/05	196	68.	M4	3	
		210	100.	M4	3	
		262	192.	F4	5	Tag-29497
		294	275.	F4	5	Tag-29496
		211	90.	M4	3	
		166	43.	-	3	
		184	62.	-	3	
		183	54.	-	3	
		183	50.	M3	3	
		176	50.	-	3	
	11/05	198	70.	-	3	
		178	52.	F3	3	
		205	86.	M4	3	

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1980					
Arctic grayling	11/05	193	76.	F3	3	
		177	58.	-	-	
		210	92.	M4	3	
		189	72.	F3	3	
		201	76.	M3	3	
		201	78.	-	3	
		175	56.	F3	3	
	12/05	225	116.	M4	3	
		190	66.	F4	3	
		190	64.	-	3	
		168	46.	F2	2	
	13/05	205	84.	F4	3	
		185	74.	F4	3	
	14/05	204	81.	F5	3	
		207	87.	M4	3	
		193	65.	-	3	
		180	-	-	3	
	15/05	201	81.	F5	3	
	16/05	197	71.	F5	3	
		186	63.	-	2	
		115	-	-	2	
	22/05	178	53.	-	3	
		166	41.	-	3	
		195	73.	-	3	
		184	67.	-	3	
		166	45.	-	3	
	14/07	215	100.	M2	3	
	18/09	203	105.	F2	2	
		225	120.	M2	3	
		219	105.	F2	3	
		271	215.	-	5	R/C-29497
		299	300.	-	5	R/C-29496
Northern redbelly dace	17/09	22(1)	<0.1			
		23(1)	0.1			
		25(2)	0.1			
		26(1)	0.2			
		27(2)	0.2			
		29(1)	0.2			
		30(1)	0.3			
		31(1)	0.2			
		32(1)	0.3			
		34(1)	0.4			
Lake chub	17/09	27	0.1			
	1981					
Arctic grayling	16/05	203	73.	-	3	
	18/05	176	56.	M3	3	
		323	385.	M3	-	
	19/05	289	260.	F4	4	
		193	83.	-	3	
		173	53.	-	3	
	20/05	261	202.	-	4	
		207	95.	F4	4	
		163	44.	F4	3	
		194	68.	F5	3	
Longnose sucker	18/05	323	385.	M3		
	19/05	374	560.	F3		R/C-29401
		314	375.	M3		
		330	455.	M3		

Table A8. In-Culvert Velocity Measurements. Creek Mile 50.7 Liard Highway Study 1980.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity
May 1	Inlet	0.25 m	33 cm	7 cm	26 cm/s	May 1	Outlet	4.0 m	24 cm	7 cm	18 cm/s	May 4	Outlet	0.1 m	28 cm	17 cm	12 cm/s
				14	32					10	19					22	12
				20	37					15	19					11	12
				26	33					20	17			0.25	26	10	12
		0.5	25	7	29			4.15	25	10	7			0.50	25	15	15
				10	29					20	14					20	15
				15	27			4.2	0	-	-			0.75	16	7	14
				20	24									1.0	8	7	11
		0.75	22	7	19	May 4	Inlet	0.1	30	7	28			1.25	12	7	10
				9	23					12	40			1.5	17	7	5
				13	22					18	43					10	10
				18	19					24	42					14	11
		1.0	8	7	17			0.25	32	7	28			1.75	26	11	4
		1.25	5	-	-					12	30					17	8
		1.5	0	Ice Edge						19	38					21	10
	Mid	0.25	15	7	19					26	34			2.0	31	8	5
		0.50	14	7	24			0.5	27	7	29			2.0	31	12	5
		0.75	13	7	28					11	33					19	5
		1.0	12	7	28					16	29					24	9
		1.25	12	7	33					22	27			2.25	30	12	5
		1.5	12	7	30			0.75	23	7	20			2.50	28	11	2
		1.75	12	7	26					9	22					22	3
		2.0	14	7	23					14	25			3.0	23	7	4
		2.25	15	7	23					18	26					9	4
				12	25			1.0	16	7	22					14	6
		2.5	15	7	18			1.25	5	5	13					19	9
				12	22			1.5	3	-	-			3.5	25	10	10
		2.75	8	7	13			1.65	0	-	-			3.75	25	10	12
		3.0	0	Ice Edge			Mid	0.25	28	11	9			4.0	23	7	10
								0.5	24	7	16					9	11
	Outlet	0.25	0	Ice Edge						10	18					14	11
		0.5	11	7	24					14	18					18	9
		0.75	8	7	20					19	20			4.25	0	-	-
		1.0	9	7	21			0.75	21	7	20	May 7	Inlet	0.1	26	7	23
		1.25	12	7	18					17	20					11	27
		1.5	19	7	10			1.0	17	7	20					16	31
				12	13					14	25					21	31
		1.75	14	7	16			1.25	13	7	23			0.25	26	7	20
				11	17			1.5	14	7	18					22	30
		1.8	Ice Edge							11	20			0.5	24	7	27
		2.6	Ice Edge					1.75	18	7	14					10	26
		2.75	10	7	12					14	18					14	24
		3.0	12	7	7			2.0	20	8	13					19	22
				11	6			2.25	20	8	12			0.75	20	8	17
		3.25	12	17	11			2.5	23	8	9			1.0	14	7	21
		3.50	26	7	15					14	12					12	22
				10	16					18	10			1.25	4	-	-
				16	18			2.75	25	10	2			1.5	0	-	-
				21	18			3.0	28	12	4						
		3.75	26	7	18			3.15	Ice Edge				Mid	0.25	36	7	3
				10	20											14	11
				16	21		Outlet	0.1	28	7	12					22	6
				21	19					11	12					29	13

(Continued . . .)

Table A8 cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity
May 7	Mid	0.75 m	36 cm	7 cm	9 cm/s	May 10	Mid	0.25 m	35 cm	14 cm	3 cm/s						
				29	13					21	7						
		1.25	36	7	5					28	10						
				14	7			0.75	35	7	9						
				22	10					28	10						
				29	10			1.25	35	7	8						
		1.75	35	7	1					14	5						
				28	4					21	10						
		2.25	33	7	1					28	9						
				15	n/c			1.75	35	7	2						
				23	n/c					28	8						
		2.75	40	-	n/c			2.5	35	7	n/c						
		3.25	38	-	n/c					28	n/c						
		3.75	36	-	n/c			3.25	35	-	n/c						
		4.25		-	-			3.75	35	-	n/c						
								4.0	35	-	n/c						
	Outlet	0.25	25	7	4			4.25	0	-	-						
				10	5												
				15	7		Outlet	0.15	21	8	16						
				20	9					17	6						
		0.75	25	10	4			0.5	21	8	4						
				20	4					12	4						
		1.25	26	7	2					17	5						
				10	3			1.0	27	7	5						
				16	3					11	3						
				20	3					22	2						
		1.75	26	7	2			1.5	21	8	1						
				20	3			2.0	22	9	1						
		2.25	26	7	1					18	2						
				10	2			2.5	23	7	3						
				15	4					14	4						
				21	4					18	4						
		2.75	20	8	5			3.0	18	7	5						
		3.25	22	7	6			3.5	19	8	5						
				9	6					11	4						
				13	7					15	4						
				18	8			4.0	19	8	6						
		3.75	22	9	5					14	5						
		4.0	21	8	7			4.25	0	-	-						
		4.25	0	-	-												
May 10	Inlet	0.15	23	7	17			After May 10 - Cross Sectional Depths Only									
				9	19												
				14	22												
				18	26												
		0.25	25	10	21												
				20	23												
		0.50	21	8	22												
				12	23												
				16	20												
		0.75	18	7	16												
		1.0	13	7	16												
		1.25	0	-	-												

[1]NOTE: All measurements start at South Side

n/c No Current
n/m No Measurement

Table A9. In-Culvert Velocity Measurements, Creek Mile 50.7 Liard Highway Study 1981.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
[1]May 3	Inlet	0.05 m	10 cm	6 cm	1 cm/s
		0.25	10	6	29
		0.5	10	6	46
		0.75	10	6	64
		1.0	7	6	94
		1.25	6	6	132
		1.5	7	6	132
		1.75	8	6	155
		2.0	9	6	162
		2.25	10	6	142
		2.5	14	6	128
		2.75	14	6	140
		3.0	10	6	116
		3.25	12	6	133
		3.5	11	6	102
		3.75	10	6	65
		4.0	10	6	25
		4.25	0	-	-
	Mid	0.15	10	6	28
		0.25	12	6	35
		0.5	12	6	47
		0.75	12	6	48
		1.0	13	6	57
		1.25	14	6	63
		1.5	14	6	64
		1.75	13	6	73
		2.0	13	6	75
		2.25	14	6	75
				10	78
		2.5	13	6	77
		2.75	13	6	72
		3.0	13	6	73
		3.25	10	6	68
		3.5	13	6	63
		3.75	13	6	56
		4.0	12	6	48
		4.15	10	6	42
		4.25	0	-	-
	Outlet	0.15	11	6	43
		0.25	13	6	58
		0.5	13	6	65
		0.75	13	6	73
		1.0	13	6	70
		1.25	12	6	70
		1.5	12	6	83
		1.75	12	6	77
		2.0	13	6	100
		2.25	11	6	99
		2.5	12	6	99
		2.75	12	6	82
		3.0 m	13 cm	6 cm	93 cm/s
		3.25	8	6	92
		3.5	13	6	72
		3.75	14	6	68
		4.0	13	6	58
		4.15	11	6	48
		4.25	0	-	-
[1]May 4	Inlet	0.25	45	18	185
		0.5	50	20	197
		0.75	55	22	263
		1.0	47	19	268
		1.25	45	18	276
		1.5	57	23	263
		1.75	52	21	227
		2.0	60	24	249
		2.25	58	23	268
		2.5	60	24	251
		2.75	60	24	251
		3.0	59	24	235
		3.25	60	24	218
		3.5	59	23	230
		3.75	52	22	149
		4.0	49	20	72
		4.1	0	-	-
	Outlet	0.25	36	22	154
		0.5	57	23	185
		0.75	58	24	203
		1.0	59	24	203
		1.25	60	24	208
		1.5	61	24	197
		1.75	60	24	201
		2.0	60	24	204
		2.25	60	24	199
		2.5	61	24	194
		2.75	61	24	201
		3.0	61	24	203
		3.25	60	24	187
		3.5	59	24	165
		3.75	55	24	151
		4.0	50	20	57
		4.1	0	-	-
May 5	Inlet	0.15	40	16	17
		0.25	45	18	43
		0.5	48	19	117
		0.75	44	17	142
		1.0	42	16	98
				32	233
		1.25	45	18	220
				36	297
		1.5 m	42 cm	16 cm	271 cm/s
		1.75	44	18	245
		2.0	48	18	245
		2.25	53	20	288
		2.5	57	23	234
		2.75	56	24	221
		3.0	58	23	185
		3.25	53	21	227
		3.5	53	21	198
		3.75	47	19	113
		4.0	45	18	82
		4.35	0	0	-
	Outlet	0.15			
		0.0	50	20	103
		0.25	48	20	146
		0.5	50	20	194
		0.75	50	20	201
		1.0	50	20	197
		1.25	51	20	199
		1.5	52	21	201
		1.75	52	21	197
		2.0	51	21	194
		2.25	51	20	187
		2.5	51	20	185
		2.75	50	20	177
		3.0	52	21	185
		3.25	52	21	173
		3.5	50	20	153
		3.75	45	18	120
		4.1	42	17	72
		4.75	0	-	-
May 6	Inlet	0.15	65	26	28
		0.25	70	26	51
		0.5	78	31	121
		0.75	77	31	136
				62	206
		1.25	79	16	136
				63	237
		1.75	76	15	173
				31	209
				62	255
		2.25	79	16	165
				63	232
		2.75	90	18	149
				36	183
				72	206
		3.25	85	17	131
				58	178
		3.75	85	17	108
				35	139

Table A9. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 6	Inlet cont'd			70	167
		4.15	82 m	17 cm	80 cm/s
				70	12
		4.25	0	-	-
May 6	Outlet	0.15	65	13	100
				51	131
		0.5	73	15	160
				29	196
				58	193
		1.0	70	23	206
				56	234
		1.5	77	15	219
				31	240
				62	252
		2.0	73	15	209
				58	152
		2.5	74	15	206
				59	245
		3.0	74	15	188
				59	211
		3.5	74	15	144
				59	191
		3.75	67	13	124
				54	119
		4.15	62	25	80
		4.35	0	-	
[1]May 7	Outlet	0.15	70	28	85
		0.25	72	28	119
		0.75	75	30	170
		1.25	70	28	185
		1.75	75	30	196
		2.25	73	29	183
		2.75	75	30	173
		3.25	74	30	165
		3.75	70	28	113
		4.05	70	28	59
		4.15	0	-	
May 8	Outlet	0.15	90	18	48
				36	64
		0.5	85	17	79
				34	83
				68	84
		1.0	90	9	96
		1.5	75	30	90
		1.75	100	40	92
		2.0	80	32	84
		2.5	100	40	92
		3.0	95	38	80
		3.5	90	36	91

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
		4.0 m	90 cm	36 cm	55 cm/s
		4.2	0	-	-
May 9	Inlet	-0.10			
		0.25	108	10	30
				20	29
				40	37
				60	53
				80	48
		0.75	105	10	43
				20	43
				40	57
				60	65
				80	63
		1.25	105	10	39
				20	44
				40	54
				60	75
				80	86
		1.5	100	10	46
				20	51
				30	79
				40	90
				60	97
				80	102
		2.0	90	10	15
				20	18
				30	6
				50	84
				80	94
		2.25	82	10	B/E
				20	6
				30	50
				40	80
				60	90
		2.75	92	10	B/E
				20	12
				30	40
				40	58
				60	74
				80	86
		3.25	95	10	15
				20	36
				30	44
				40	52
				60	68
				80	84
		3.75	90	10	28
				20	38
				40	50
				60	44

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
				80	30
		4.0	0	-	-
	Mid	0.25 m	145 cm	20 m	11 cm/s
				40	31
				80	25
				120	25
		0.75	150	20	35
				40	47
				80	38
				120	26
		1.25	155	10	3
				20	20
				40	34
				80	46
				120	39
		1.75	150	20	38
				40	40
				80	45
				120	46
		2.25	145	20	38
				40	37
				80	37
				120	40
		2.75	130	20	35
				40	34
				80	36
				120	37
		3.25	112	20	34
				40	41
				80	38
				100	31
		3.75	98	20	29
				40	31
				80	30
		4.1	95	40	24
		4.25	0	-	-
	Outlet	0.15	90	10	47
				20	40
				40	53
				80	47
		0.5	95	20	35
				40	60
				60	59
				80	58
		1.0	95	10	41
				20	37
				40	60
				80	61
		1.5	93	10	35
				20	37
				40	46

Table A9. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 9 cont'd	Outlet	2.0 m	100 cm	80	62
				10 cm	50 cm/s
				20	47
				40	60
				80	56
		2.5	69	10	54
				20	59
				40	57
				80	63
		3.0	95	10	37
				20	51
				40	54
				80	61
		3.5	104	10	43
				20	36
				40	58
				80	59
		4.0	105	20	42
				40	44
				80	45
		4.2	0	-	-
May 11	Inlet	0.25	95	10	24
				20	28
				40	46
				80	46
		0.75	100	10	39
				20	48
				40	50
				80	46
		1.25	95	10	33
				20	32
				40	46
				80	68
		1.75	90	10	38
				20	51
				40	68
				80	38
		2.25	70	10	7
				20	55
				40	74
		2.75	70	10	39
				20	52
				40	63
				60	71
		3.25	85	10	14
				20	33
				40	53
				60	69
		3.75	85	10	40
				20	53
				40	64
		4.20 m	81 cm	60	29
				20 cm	37 cm/s
				40	37
				70	25
		4.5	0	-	-
	Mid	0.25	170	10	4
				10	28
				80	26
				150	13
		1.0	170	20	42
				80	38
				150	18
		1.74	167	20	39
				40	42
				80	37
				120	37
		2.5	170	20	20
				40	34
				80	25
				150	33
		3.25	160	20	13
				40	23
				80	35
				150	28
		3.5	128		n/m
		3.75	108		n/m
		4.0	95	20	27
				40	19
		4.0	0	-	
	Outlet	0.25	95	20	46
				40	58
				80	45
		0.5	80		n/m
		0.75	95		n/m
		1.0	90	10	38
				20	54
				40	58
				80	53
		1.25	90		n/m
		1.5	90		n/m
		1.75	90	20	42
				40	45
				80	58
		2.0	95		n/m
		2.25	85		n/m
		2.5	64	10	45
				30	49
				50	56
		2.75	90		n/m
		3.0	90		n/m
		3.25 m	93 cm	10 cm	36 cm/s
				20	47
				40	45
				80	56
		3.5	84		n/m
		3.75	95		n/m
		4.0	95	10	17
				20	44
				40	56
				80	53
		4.3	0		-
May 16	Inlet	0.25	65	10	17
				20	30
				40	32
				60	29
		0.75	70	10	21
				20	31
				40	40
				60	38
		1.25	70	10	26
				20	25
				40	28
				60	34
		1.75	60	10	30
				20	34
				40	45
		2.0	55	10	20
				20	13
				40	6
				52	53
		2.5	40	10	B/E
				20	26
				35	47
		3.0	95	10	17
				20	36
				35	41
		3.25	60	10	4
				20	26
				40	43
				55	52
		3.75	60	10	38
				30	42
				40	41
				55	32
		4.2	52	10	26
				20	33
				40	29
		4.3	0	-	-
	Mid	0.3	135	20	14
				40	21

Table A9. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 16 cont'd	Inlet			80	17					40	23					30	37
				120	13					80	18					50	34
		0.75 m	135 cm	10 cm	16 cm/s			3.75 m	85 cm	10 cm	14 cm/s			2.25	60		n/m
				40	19					40	16			2.5 m	58 cm	10 cm	1 cm/s
				80	22					80	14					30	40
				120	16			4.2	62	25	16					50	36
		1.25	140	20	20			4.3	0	-	-			2.75	39		n/m
				40	24									3.0	60	10	11
				80	19		Outlet	0.15	55	10	33					20	25
				120	18					20	37					40	40
		1.75	137	10	15					40	37					55	41
				40	18			0.5	51	10	27			3.25	64		n/m
				80	14					20	37			3.5	62	10	17
				120	14					50	36					40	37
		2.25	125	20	14			1.0	60	20	35					55	35
				40	18					40	39			3.75	68		n/m
				80	15					55	38			4.0	65	10	12
				120	14			1.25	60		n/m					20	30
		2.75	117	10	14			1.5	60	10	27					40	40
				40	18					20	26					60	37
				80	15					55	37			4.25	66		n/m
				110	16			1.75	57		n/m			4.3	0	-	-
		3.25	102	20	18			2.0	53	10	37						

[1]Note: All measurements on ice.
n/c no current
n/m no measurement
B/E back eddy
*All shore measurements start at 0.00 m except where indicated.

Table A10. Growth in length by summary age class for Arctic grayling from Creek Mile 51.9, 1978 - 1981.

Year	Age Class	Sampling Period	n	Mean Length (mm)	Standard Deviation	Range (mm)
1978	0	IV	3	72.0	5.6	67-78
	1	I	5	74.8	4.0	69-78
	1	IV	3	130.0	16.1	115-147
	2	IV	14	196.2	21.7	168-238
	3	I	12	221.2	18.0	195-249
	3	IV	2	241.5	9.2	235-248
	4	I	13	264.4	32.9	223-333
	4	IV	2	267.0	4.2	264-270
	5	I	4	279.8	8.4	273-292
	5	IV	1	309.0	-	-
1979	0	III	1	48.0	-	-
	0	IV	2	49.0	9.9	42-56
	2	I	1	174.0	-	-
	2	IV	6	192.8	10.0	183-212
	3	III	4	231.5	3.8	226-234
	3	IV	1	257.0	-	-
	4	I	1	265.0	-	-
	4	III	2	258.0	1.4	257-259
1980	0	II	6	48.0	4.7	44-55
	0	III	2	68.0	1.4	67-69
	0	IV	5	72.6	5.3	66-79
	1	I	4	80.5	5.3	76-88
	2	I	2	182.0	8.5	176-188
	2	III	1	204.0	-	-
	2	IV	1	183.0	-	-
	3	I	50	200.9	21.6	169-246
	3	II	2	215.0	2.8	213-217
	3	IV	2	211.5	2.1	210-213
	4	I	21	246.8	18.8	216-280
	5	I	11	279.5	20.3	242-306
	5	III	1	287.0	-	-
	6	I	4	312.0	15.1	296-331

1981 No Arctic grayling samples collected in 1981.

SAMPLING PERIOD INDEX

Sample Period	Study Year	1978	1979	1980	1981
I		May 14-June 9	May 17-June 4	May 4-23	May 15-20
II		N/A	July 10-11	July 13-14	N/A
III		N/A	August 19-20	August 17-18	N/A
IV		Sept 20-24	Sept 8-10	Sept 16-18	N/A

Table A11. Individual fish data from Creek Mile 51.9 Liard Highway Study 1978-1981.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Arctic grayling	14/05	200	75.	F4	3	
	15/05	236	110.	M4	3	
		235	120.	F4	3	
		212	70.	F2	3	
	16/05	223	110.	M4	4	
	17/05	209	100.	M4	3	
		292	260.	F4	5	
	20/05	286	200.	M5	4	
	21/05	237	110.	M5	4	
	22/05	289	250.	F5	4	
		249	140.	M5	3	
		239	130.	-	4	
	25/05	274	180.	-	4	
	29/05	237	130.	F5	3	
	01/06	233	100.	M5	3	
	02/06	225	110.	M2	4	
		304	250.	M5	4	
		333	370.	M5	4	
	03/06	267	190.	F5	4	
	04/06	277	250.	M5	5	
		273	200.	F5	5	
		235	140.	M5	4	
	06/06	263	200.	M5	4	
	07/06	262	270.	M5	4	
		224	140.	M5	3	
		229	140.	M5	3	
		195	100.	F2	3	
		198	120.	F2	3	
		277	246.	F2	5	
		74	3.7	-	1	
		74	3.5	-	1	
		79	4.1	-	1	
		69	2.9	-	1	
		78	4.2	-	1	
	20/09	216	110.	F2	2	
		219	110.	M2	2	
		128	16.	F1	1	
		238	146.	M2	2	
		309	330.	M2	5	
		235	130.	F2	3	
		214	100.	F1	2	
		204	100.	F2	2	
		208	95.	F2	2	
	21/09	248	200.	-	3	
		264	220.	-	4	
		270	240.	F2	4	
		200	90.	M2	2	
		168	60.	M1	2	
		172	70.	M1	2	
		201	100.	F2	2	
		175	60.	F1	2	
		176	70.	F1	2	
		178	70.	M1	2	
		178	70.	M1	2	
	22/09	147	31.	M1	1	
		115	15.	F1	1	
	23/09	71	3.8	F1	0	
		67	2.4	F1	0	
		78	4.3	M1	0	
Longnose sucker	14/05	318	350.	M4		
	15/05	354	525.	F3		
		330	380.	M4		
		347	480.	F3		
		365	525.	F3		
	16/05	358	500.	F3		
		319	360.	M4		
	17/05	356	480.	F3		
		286	260.	M3		
		344	420.	M3		
		345	430.	M3		
		307	350.	M3		
		331	370.	M3		
		386	470.	M3		
		339	410.	M3		
		330	400.	F3		
		341	416.	M3		
		329	416.	F3		
		333	410.	F3		
		326	390.	M3		
		315	340.	M3		
		324	380	F3		
		310	320.	M3		
		326	350.	M3		
		346	390.	F3		
		308	290.	M3		
		332	380.	F3		
		337	380.	M3		
		359	470.	F3		
		336	400.	F3		
	18/05	335	390.	-		
		359	380.	F3		
		336	410.	F3		
		324	300.	M4		
		343	380.	F3		
		342	-	F3		
		341	410.	M4		
		359	450.	F3		
		354	480.	F3		
		351	460.	F3		
		358	460.	F3		
		333	370.	M3		
		362	470.	F3		
		328	400.	F3		
		335	400.	F3		
		328	310.	M3		
		332	350.	M4		
		357	460.	F4		
		320	320.	M4		
		332	390.	F4		
		356	530.	M4		
		323	370.	F3		
		358	490.	M4		
		328	380.	M4		
		321	340.	M4		
		313	330.	F3		
		350	400.	M3		
		304	280.	M3		
		286	230.	M3		
	1905	285	230.	M4		
		267	190.	M3		
		285	240.	M4		

Table A11. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Longnose sucker	19/05	347	410.	F3		
		345	420.	F3		
		258	160.	M4		
		358	430.	F3		
		326	340.	M3		
		311	310.	M3		
		341	380.	F3		
		361	470.	F3		
		334	350.	M3		
		347	380.	F3		
		321	290.	M4		
		306	280.	M3		
		319	290.	M3		
		340	380.	F3		
		314	280.	M4		
		368	480.	F3		
		302	280.	M4		
		327	310.	M4		
		341	410.	M4		
		345	420.	F3		
	20/05	297	290.	M4		
		335	370.	F3		
		331	360.	F3		
		341	370.	F3		
		348	390.	F3		
		260	176.	M4		
	21/05	348	460.	F3		
		357	480.	F3		
		339	390.	F3		
		289	250.	F3		
		336	420.	F3		
		302	270.	F3		
		288	220.	M4		
	22/05	338	430.	F3		
		333	420.	F3		
		318	370.	F3		
		324	370.	M4		
		291	270.	F3		
		352	450.	F3		
		325	356.	M4		
		326	346.	M4		
		331	380.	M4		
		317	336.	M4		
	23/05	331	360.	F3		
	24/05	338	380.	M4		
		324	316.	M4		
		347	400.	M4		
		337	380.	M4		
		352	400.	F3		
		317	380.	M4		
		357	460.	F3		
		341	350.	M4		
	25/05	363	480.	F3		
		324	330.	M4		
		323	340.	M4		
		320	310.	M4		
		346	420.	F3		
		322	380.	M4		
		329	360.	M4		
		354	470.	M4		
		302	290.	M4		
		284	220.	M4		
Longnose sucker	25/05	348	460.	F3		
		301	370.	F3		
		293	230.	M4		
		331	356.	M4		
		324	360.	M4		
		322	300.	M4		
		290	250.	M4		
	26/05	314	330.	M4		
		323	380.	M4		
		291	260.	M4		
		247	140.	M4		
		252	170.	M4		
	28/05	322	300.	M4		
		335	400.	F3		
		326	320.	M4		
		310	320.	M4		
		315	320	M4		
		293	280.	M4		
		328	330.	M4		
		246	150.	M4		
		300	270.	F3		
		331	376.	M4		
	29/05	324	380.	M4		
	31/05	288	250.	M4		
		284	250.	F3		
	01/06	343	410.	F3		
		336	400.	F3		
		328	340.	M4		
		332	360.	M4		
	05/06	64	2.4	0		
		65	2.1	0		
	06/06	251	180.	M5		
	22/09	118	19.1	F1		
		95	10.1	F1		
		81	5.8	F1		
		82	6.9	F1		
		74	4.6	F1		
		34(1)	0.4	0		0
		36(3)	0.4-0.5	0		0
		37(3)	0.4-0.6	0		0
		38(2)	0.5	0		0
		39(2)	0.5-0.6	0		0
		40(3)	0.6-0.8	0		0
		42(4)	0.7-0.9	0		0
		43(4)	0.8-0.9	0		0
		44(2)	0.8-0.9	0		0
		45(1)	1.1	0		0
		48(1)	1.2	0		0
	23/09	29(1)	0.2	0		0
		34(2)	0.3	0		0
		35(2)	0.4	0		0
		36(3)	0.4-0.5	0		0
		37(4)	0.4-0.5	0		0
		38(3)	0.5-0.6	0		0
		39(4)	0.5-0.6	0		0
		40(4)	0.6	0		0
		41(4)	0.6-0.8	0		0
		42(2)	0.8	0		0
		43(3)	0.7-0.8	0		0
		44(3)	0.8-0.9	0		0
		45(1)	0.9	0		0
		66(1)	3.1	0		0
		74(1)	4.3	0		0

Table A11. Cont'd

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Northern pike	14/05	527	1150.	F4	6	
	15/05	314	190.	M4	3	
	17/05	479	720.	M4	5	
		550	1250.	F3	5	
		359	300.	M4	3	
	18/05	513	820.	M4	8	
		473	700.	M4	6	
		539	1225.	F3	7	
		498	840.	M3	6	
		376	330.	F3	4	
	19/05	455	570.	M4	-	
		365	310.	M4	3	
		358	270.	M4	3	
		427	510.	M3	4	
	20/05	535	1125.	M3	7	
	22/05	384	420.	M5	4	
	23/05	408	430.	M3	3	
		423	480.	M4	3	
		388	410.	F4	3	
	25/05	262	290.	-	3	
	28/05	373	280.	-	5	
	04/06	344	320.	-	4	
		438	500.	F5	7	
		397	400.	M2	-	
	21/09	250	125.	M2	2	
		291	220.	F1	2	
		239	110.	F1	2	
		217	80.	F1	2	
White sucker	22/05	343	490.	F3	-	
Slimy sculpin	22/09	50	1.3	-	2	
		94	11.3	F2	4	
		56	2.0	-	2	
		112	14.8	F2	5	
		96	11.9	F2	4	
		110	14.4	M2	4	
		102	13.2	M2	4	
		92	10.0	F2	4	
		77	5.8	F2	3	
		92	9.0	F2	4	
		79	5.9	F2	3	
		80	6.6	F2	3	
		100	14.4	M2	4	
		88	8.0	M2	3	
		52	1.4	F1	2	
		91	10.1	F2	4	
		49	2.0	M1	1	
		56	2.0	M1	2	
		35	0.4	F1	1	
		47	1.1	F1	1	
		47	0.7	M1	1	
		42	0.7	M1	1	
		44	0.9	F1	1	
		40	0.6	M1	1	
		36	0.5	F1	-	
		37	0.5	M1	-	
	23/09	52	1.4	M1	2	
		37	0.5	F1	1	
		50	1.1	F1	1	
		45	0.9	F1	1	
		46	1.0	F1	1	
Slimy sculpin	23/09	49	1.1	F1	1	
		49	1.2	F1	1	
		49	1.1	M1	1	
		58	1.8	M1	2	
		55	1.6	M1	1	
		34	0.4	M1	0	
		35	0.4	M1	6	
		51	1.4	M1	1	
		50	1.0	F1	1	
		45	1.0	F1	1	
		117	22.7	M2	4	
		93	10.9	M2	4	
		105	14.5	M2	4	
		97	11.2	M2	4	
		81	7.0	M2	3	
		98	12.3	M2	4	
		81	6.0	M2	3	
		103	13.8	F2	4	
		101	13.8	M2	4	
		93	11.4	M2	3	
		112	20.2	M2	4	
		101	13.4	F2	-	
		98	12.6	M2	3	
		119	21.5	F2	5	
		95	11.4	M2	4	
		93	10.2	M2	3	
	1979					
Arctic grayling	17/05	265	210.	-	4	Tag-29372
	26/05	174	-	M2	2	
	03/06	367	590.	M5	6	
	20/08	257	185.3	F2	4	
		226	112.3	M2	3	
		234	140.	F2	3	
		234	142.	F2	3	
		259	198.	M2	4	
		232	128.	M2	3	
		48	0.7	0	0	
	09/09	42	0.4	0	0	
		56	1.1	0	0	
		257	166.	M2	3	
		192	69.	F1	2	
		191	67.	M1	2	
	10/09	212	102.	M2	2	
		183	60.	M2	2	
		191	74.	F2	2	
		188	76.	F2	2	
Longnose sucker	23/05	363	460.	F3		
	27/05	344	440.	F3		Tag-29416
	30/05	342	460.	F4		Tag-29427
	31/05	292	290.	M4		Tag-29437
	01/06	438	756.	-		Tag-29442
	03/06	310	370.	F3		
	04/06	352	450.	-		Tag-29452
		338	380.	-		Tag-29453
		338	400.	-		Tag-29454
	11/07	55	1.3	0	1	
		53	1.1	0	1	
		46	0.8	0	1	
		53	1.2	0	1	
	20/08	32	0.3	0	0	

Table A11. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1979					
Longnose sucker	09/09	40	0.6	0	0	
		43	0.6	0	0	
		27	0.2	0	0	
		29	0.2	0	0	
		116	17.0	-		
	10/09	34	0.2	0	0	
		32	0.2	0	0	
		30	0.1	0	0	
		34	0.3	0	0	
		30	0.2	0	0	
		165	44.	-		
		182	62.	-		
		178	66.	-		
		161	48.	-		
		188	72.	-		
		157	42.	-		
		164	50.	-		
		174	54.	-		
Northern pike	26/05	665	2200.	F4	8	
	28/05	633	2870	F4	9	
	09/09	145	12.4	-	1	
		150	16.6	-	1	
	1980					
Arctic grayling	04/05	221	95.	-	3	
		275	210.	M3	4	
		193	75.	-	3	
		261	205.	-	5	
	05/05	223	112.	-	4	
		272	205.	M3	5	Tag-29455
		316	112.	F3	6	Tag-29456
		278	230.	-	-	Tag-29459
		241	135.	M3	3	
	06/05	208	100.	-	3	
		284	238.	M3	5	Tag-29460
		305	335.	F3	6	Tag-29461
		246	165	-	4	
		306	295.	M3	5	Tag-29462
		245	170.	M3	4	
		246	160.	-	3	
		223	105.	-	3	
		226	115.	-	3	
	07/05	251	160.	F3	4	Tag-29464
		333	450.	F3		Tag-29465
		296	245.	F3	5	Tag-29466
		227	115.	-	3	
		241	135.	-	4	
		222	100.	M3	3	
	08/05	218	95.	-	4	
		246	160.	M3	4	Tag-29467
		296	300.	F3	5	Tag-29468
		270	205	M3	4	Tag-29469
	09/05	280	230.	F3	4	Tag-29472
		331	405.	F4	6	Tag-29500
		238	140.	-	4	
		210	95.	-	-	
		225	170.	M3	4	
		214	105.	-	3	
	10/05	206	105.	-	3	
Arctic grayling	10/05	233	137.	F3	3	
		253	200.	F3	4	
		286	255.	F4	5	Tag-29491
		302	355.	F3	5	Tag-29492
	11/05	255	175.	M4	4	Tag-29488
		280	215.	M4	4	Tag-29487
		296	280.	F3	6	Tag-29486
		260	205.	F4	5	Tag-29485
		204	86.	F4	3	
		185	60.	M4	3	
		181	62.	-	3	
		174	54.	-	3	
		181	50.	-	3	
	12/05	225	62.	-	3	
		176	54.	-	3	
		174	52.	-	3	
		184	62.	F1	3	
		241	145.	F4	4	Tag-29479
		197	75.	M4	3	
		216	105.	F2	3	
	13/05	269	195.	F4	5	R/C-29377
		230	125	M4	3	
		188	66.	M4	3	
		188	65.	-	3	
	14/05	178	57.	-	3	
		192	68.	-	3	
		196	72.	F4	3	
		216	95.	-	4	
		227	118.	F2	3	
		236	142.	F5	4	
		218	107.	M5	3	
		238	138.	-	3	
	15/05	184	75.	-	3	
		203	73.	-	3	
		204	83.	M5	3	
		169	49.	F1	3	
		236	120.	-	4	
		240	143.	F3	4	
	16/05	177	56.	-	3	
		174	54.	-	-	
		197	66.	M5	3	
		174	53.	-	3	
		171	49.	F1	3	
		188	63.	F1	3	
		190	64	F5	3	
		180	57.	F1	3	
	17/05	259	180.	-	4	
		187	63.	-	3	
		188	58.	-	2	
		218	103.	-	3	
	18/05	222	98.	-	3	
		187	62.	-	3	
		172	46.	-	3	
		188	66.	-	3	
	19/05	242	134.	-	5	
		176	58.	-	2	
	20/05	222	105.	M5	3	
		80	-	-	1	
	21/05	78	-	-	1	
		88	-	-	1	
		76	-	-	1	

Table A11. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1980					
Arctic grayling	14/07	217	126.	M2	3	
		213	115.	F2	3	
		46	0.8	0	0	
		45	0.7	0	0	
		53	1.2	0	0	
		55	1.3	0	0	
		44	0.7	0	0	
		45	0.7	0	0	
	18/08	287	295.	F2	5	
		204	92.	M2	2	
		69	3.5	0	0	
		67	3.3	0	0	
	17/09	77	3.8	0	0	
	18/09	210	105.	M2	3	
		183	65.	F2	2	
		213	105.	F2	3	
		79	4.5	0	0	
		66	2.8	0	0	
		71	3.3	0	0	
		70	3.2	0	0	
Longnose sucker	08/05	197	95.	-		
	10/05	307	335.	M4		Tag-29495
		321	385	M4		Tag-29494
		303	325.	M4		Tag-29493
	11/05	365	500.	F3		Tag-29484
		359	560.	F3		Tag-29483
		386	520.	F3		
		325	440	M4		
		306	320	M4		
		334	445.	M4		
	12/05	355	550.	F3		
		301	300.	F3		
		334	380.	M4		
		328	400.	M4		
		360	450.	F3		
		271	215.	M4		
		314	395.	M4		
		351	450.	F3		
		281	260.	M4		
		295	305.	M4		
	13/05	360	520.	F3		
		342	450.	F3		
	14/05	283	250.	M4		
		331	390.	F3		
	15/05	165	47.	-		
		262	218.	M4		
	17/05	273	205.	M4		
	18/05	72	3.8	-		
		65	3.2	-		
	20/05	144	32.	-		
	21/05	58	1.8	-		
	14/07	72	3.6	-		
		58	2.0	-		
		46	0.9	-		
		15(1)	-	-		
		16(2)	-	-		
Northern pike	13/05	450	800.	F3	-	
		454	720.	M4	-	
	18/09	375	415.	F2	-	
		282	-	M2	-	
		220	90.	M1	-	
Slimy sculpin	17/05	76	5.8	-	3	
	19/05	90	7.5	F2	4	
		85	7.6	M2	4	
	20/05	88	6.0	F2	3	
	17/09	49	0.9		1	
		44	0.7		1	
		47	0.9		-	
		41	0.6		1	
		41	0.6		1	
		41	0.5		-	
		47	0.8		-	
		40	0.5		1	
		43	0.6		-	
		48	0.9		-	
		45	0.7		-	
		89	8.4	F2	-	
	18/09	118	22.9	F2	3	
Northern redbelly dace	17/09	40	0.7	-	-	
		43	0.8	-	-	
	1981					
Longnose sucker	18/05	342	455	-		
		321	375.	-		
		323	400.	F3		R/C-29494
	19/05	322	380.	F3		
		340	450.	M3		
	20/05	-	-	F3		
Northern pike	18/05	509	870.	M3	5	
	19/05	458	670.	M3	5	

Table A12. In-Culvert Velocity Measurements, Creek Mile 51.9 Liard Highway Study 1980

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 1	Inlet	0.1 m	12 cm	7 cm	21 cm/s
		0.6	27	7	25
				11	29
				16	29
				22	33
		1.1	28	12	34
		1.6	25	7	28
				10	32
				15	36
				20	39
		2.1	20	8	29
		2.6	10	7	34
		3.1	15	7	25
		3.6	13	7	22
		4.1	18	7	19
		4.25	8	-	-
	Mid	0.1	24	7	27
				10	24
				15	25
				20	24
		0.6	27	7	30
				9	31
				13	31
				18	32
		1.1	21	7	26
				8	27
				12	32
				16	32
		1.6	17	7	29
		2.1	14	7	29
		2.6	12	7	28
		3.1	23	7	24
				9	26
				14	27
				19	33
		3.6	28	11	16
		4.1	34	14	21
		4.2	0	-	-
	Outlet	0.1	23	7	19
				10	21
				14	19
				18	19
		0.25	23	7	19
				10	21
				14	21
				18	22
		0.75	22	7	22
				10	22
				14	25
				18	26
May 1	Outlet	1.25 m	23 cm	7 cm	21 cm/s
				10	24
				14	24
				18	25
		1.75	25	7	19
				10	21
				15	21
				20	23
		2.25	25	10	21
				15	22
				20	25
		2.75	24	7	25
				10	25
				15	26
				20	29
		3.25	25	10	26
				15	27
				20	24
		3.75	23	7	23
				10	24
				15	26
				20	26
		4.25	21	7	19
				13	20
				17	21
		4.4	0	-	-
May 4	Inlet	0.25	32	7	3
				13	2
				19	3
				26	5
		0.5	29	12	5
		0.75	24	7	8
				10	7
				14	5
				19	8
		1.0	18	7	9
		1.5	22	7	13
				9	14
				13	16
				18	17
		2.0	32	7	10
				25	26
		2.5	32	7	12
				13	21
				19	24
				25	25
		3.0	33	7	16
				26	24
		3.5	40	8	8
				16	12
				24	18
				32	21
May 4	Inlet	3.75 m	46 cm	9 cm	8 cm/s
				37	21
		4.0	52	11	8
				21	14
				31	12
				42	15
		4.75	0	-	-
	Mid	0.25	55	11	7
				22	7
				33	9
				44	12
		0.5	56	11	10
				45	12
		1.0	53	10	7
				21	10
				32	12
				42	10
		1.5	53	11	9
				42	10
		2.0	54	11	8
				22	10
				33	11
				43	13
		2.5	50	10	6
				40	12
		3.0	44	9	6
				18	6
				26	9
				35	7
		3.5	36	7	6
				29	4
		4.0	48	9	4
				19	4
				29	5
				38	4
		4.25	0	-	-
	Outlet	0.25	46	18	2
		0.75	50	10	4
				20	4
				30	5
				40	5
		1.25	58	11	7
				46	8
		1.75	67	13	6
				26	6
				40	9
				54	10
		2.25	67	26	7
		2.75	68	14	3
				27	3
				41	7
				54	9

(Continued . . .)

Table A12. cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 4	Outlet	3.25 m	73 cm	15 cm	4 cm/s
				58	9
		3.75	78	15	4
				31	5
				47	6
				63	5
		4.25	71	14	2
				57	3
		4.4	0	-	-
May 7	Inlet	0.25	60	12	5
				24	10
				36	10
				46	8
		0.75	53	11	3
				42	13
		1.25	46	9	9
				18	16
				28	10
				37	17
		1.75	39	8	8
				31	21
		2.25	48	10	10
				19	10
				29	9
				38	15
		2.75	47	10	2
				37	9
		3.25	47	9	n/c
				19	n/c
				29	1
				38	4
		3.75	47	9	n/c
				38	1
		4.25	0	-	-
	Mid	0.25	94	19	3
				38	5
				56	6
				75	2
		0.75	90	18	10
				72	6
		1.25	90	18	1
				36	4
				54	2
				72	6
		1.75	88	18	4
				70	4
		2.25	85	17	3
				34	2
				51	3
				68	2
		2.75	90	18	n/c
				75	2
May 7	Mid	3.25 m	87 cm	17 cm	n/c cm/s
				35	n/c
				52	3
				70	3
		3.75	78	16	n/c
				62	n/c
		4.3	0	-	-
	Outlet	0.25	100	20	n/c
				40	1
				60	1
				80	1
		0.75	97	20	1
				60	1
		1.5	100	20	1
				80	2
		2.25	102	20	1
				40	1
				60	2
				80	3
		3.0	105	21	1
				85	2
		3.75	107	21	2
				42	3
				80	2
		4.25	0	-	-
May 10	Inlet	0.5	65	13	B/E
				26	B/E
				39	B/E
				52	B/E
		1.0	50	20	n/c
		1.5	50	10	n/c
				40	n/c
		2.0	50	10	n/c
				40	n/c
		2.5	50	10	7
				20	10
				30	8
				40	4
		3.0	54	11	11
				44	11
		3.5	55	11	15
				22	19
				33	20
				44	18
		4.0	66	13	11
				26	16
				40	7
				52	17
		4.25	0	-	-
May 10	Mid	0.5 m	100 cm	40 cm	4 cm/s
		1.0	105	21	1
				42	2
				63	2
				84	1
		1.5	105	42	1
		2.0	100	20	1
				40	2
				60	2
				80	1
		2.5	94	38	2
		3.0	93	18	n/c
				37	1
				55	2
				73	1
		3.5	103	41	n/c
		4.0	103	41	n/c
		4.25	0	-	-
	Outlet	0.5	109	44	1
		1.0	110	22	1
				44	3
				66	2
				88	2
		1.5	110	44	1
		2.0	105	21	2
				42	2
				63	2
				84	2
		2.5	100	40	2
		3.0	110	22	1
				44	2
				66	2
				88	3
		3.5	115	45	2
		4.3	0	-	-

After May 10 - Cross Sectional Depths Only

[1]NOTE: All measurements start at North side.

n/c No Current
n/m No Measurement
B/E Backeddy

Table A13. In-Culvert Velocity Measurements, Creek Mile 51.9 Liard Highway Study 1981.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
[1]May 3	Inlet	0.15 m	26 cm	6 cm	32 cm/s		Outlet	0.15 m	12 cm	6 cm	55 cm/s			1.75 m	30 cm	6 cm	169 cm/s
				11	34			0.25	14	6	88					12	183
				21	56					12	73					18	102
		0.25	24	10	85			0.75	15	6	84					24	138
		0.5	18	6	116			1.0	14	6	89			2.0	28	6	170
				14	127					12	94					11	200
		0.75	18	6	119			1.25	13	6	85					17	199
				14	119			1.5	15	6	85					23	178
		1.0	15	6	124			1.75	14	6	89			2.25	25	6	160
		1.25	15	6	123			2.0	14	6	81					10	179
				12	130					12	87					13	183
		1.5	15	6	116			2.25	15	6	71					20	184
		1.75	15	6	108			2.50	15	6	72			2.5	25	6	153
		2.0	15	6	89			2.75	15	6	75					10	162
				12	90			3.0	15	6	77					13	160
		2.25	13	6	79			3.25	13	6	76					20	155
		2.5	12	6	79			3.5	14	6	67			2.75	25	6	127
		2.75	11	6	69			3.75	15	6	74					10	139
		3.0	8	6	62			4.0	15	6	81					16	131
		3.25	8	6	51			4.25	13	6	77					20	107
		3.5	7	6	33			4.35	0	-	-			3.0	21	8	103
		3.75	7	6	19											12	115
		4.0	6	6	15	May 4	Inlet	0.15	38	7	9					16	105
		4.2	0	-	-					14	105			3.25	22	7	79
										21	143					17	70
	Mid	0.15	10	6	79			0.25	36	7	116			3.5	18	6	56
		0.25	12	6	103					14	180					13	69
		0.5	15	6	110					21	162			3.75	16	7	51
				12	126					28	120					12	38
		0.75	19	6	92			0.50	33	7	147			4.0	16	6	25
				15	108					14	205					12	28
		1.0	16	7	92					21	198			4.25	0	-	-
		1.25	16	6	105					27	120						
				13	109			0.75	34	7	157		Mid	0.25	26	6	110
		1.5	14	6	78					14	204					20	141
		1.75	13	6	112					21	207			0.5	28	6	138
		2.0	13	6	93					27	203					12	168
		2.25	13	6	90			1.0	32	7	175					18	175
		2.5	14	6	71					14	204					24	142
				11	97					21	228			0.75	22	6	178
		2.75	15	6	73					27	150					21	208
				13	90			1.25	30	6	168			1.0	28	6	183
		3.0	16	6	79					12	197					11	218
		3.25	16	6	77					18	200					18	228
				13	85					24	215					21	227
		3.55	15	6	65			1.5	30	6	157			1.25	25	6	110
		3.75	15	6	82					12	184					20	157
		4.0	15	6	73					18	197			1.5	24	5	190
				12	57					24	208					20	180
		4.25	0	-	-												

Table A13. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 4 cont'd	Mid	1.75 m	23 cm	6 cm	218 cm/s
				19	197
		2.0	25	5	220
				20	195
		2.25	22	6	224
				19	157
		2.5	23	6	200
				19	178
		2.75	23	6	197
				19	177
		3.0	24	6	150
				18	192
		3.5	23	6	147
				19	153
		3.75	30	6	118
				16	150
				25	122
		4.0	27	6	90
				21	97
		4.15	25	10	63
		4.25	0	-	-
	Outlet	0.15	30	6	64
				24	78
		0.25	34	6	97
				25	107
		0.75	34	6	118
				19	158
		1.0	35	7	118
				14	173
				21	180
				28	170
		1.25	35	7	144
				28	190
		1.5	35	7	139
				27	133
		1.75	34	7	138
				27	190
		2.0	34	7	138
				27	190
		2.0	34	7	138
				27	198
		2.25	34	7	205
				27	147
		2.5	35	7	148
				28	189
		2.75	34	7	132
				14	169
				28	193
		3.0	33	7	142
				27	180
		3.25 m	32 cm	7 cm	143 cm/s
				27	159
		3.5	31	7	119
				26	156
		3.75	35	7	123
				27	144
		4.0	35	7	100
				28	100
		4.25	28	7	84
				22	83
		4.35	0	-	-
May 5	Inlet	0.25	53	21	231
		0.5	55	22	273
		0.75	42	19	260
		1.0	48	19	276
		1.25	45	18	283
		1.5	44	18	276
		1.75	42	17	257
		2.0	38	15	214
		2.5	38	15	185
		2.75	29	12	170
		3.0	46	19	113
				37	160
		3.25	49	20	113
				40	130
		3.5	43	18	142
		3.75	39	16	54
		4.0	39	16	17
		4.25	0	-	-
	Outlet	0.25	43	18	67
		0.5	48	19	98
		0.75	48	19	139
		1.0	48	19	198
		1.25	50	20	224
		1.5	50	20	234
		1.75	48	19	232
		2.0	48	19	227
		2.25	48	19	224
		2.5	49	19	214
		2.75	49	19	206
		3.0	50	20	220
		3.25	50	20	180
		3.5	48	19	140
		3.75	48	19	116
		4.0	48	19	69
		4.25	47	19	39
		4.3	0	-	-
May 6	Outlet	0.15	85	34	124
		0.25 m	85 cm	34 cm	240 cm/s
				68	180
		1.0	90	72	288
		1.5	95	76	324
		2.0	100	90	340
		2.5	100	90	340
		3.0	98	90	288
		3.5	95	76	196
		4.0	87	35	134
				70	118
		4.25	0	-	-
May 7	Outlet	0.15	95	38	142
		0.50	97	39	234
		1.0	96	77	294
		1.5	93	90	355
		2.0	90	80	345
		2.5	92	85	209
		3.0	97	78	252
		3.5	98	39	201
		4.0	90	17	88
				24	62
		4.25	0	-	-
May 8	Outlet	0.15	110	44	149
		0.25	115	46	245
		0.5	123	49	286
		1.0	125	50	301
		1.5	125	50	273
		2.0	125	50	247
		2.5	125	50	252
		3.0	125	50	245
		3.5	112	45	283
		4.0	105	42	191
		4.2	0	-	-
May 10	Inlet	-0.10			
		0.15	127	10	16
				20	16
				40	26
				80	37
		0.25	120	80	64
		0.5	125	10	17
				20	21
				40	30
				80	55
				120	83
		1.0	135	10	24
				20	36
				40	42
				80	59

Table A13. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 10 Cont'd	Inlet	1.5 m	143 cm	120	102
				10 cm	18 cm/s
				20	28
				40	57
				80	70
				120	101
		2.0	147	10	28
				20	42
				40	84
				80	96
				120	115
		2.5	149	10	46
				20	68
				40	101
				80	114
				120	137
		3.0		10	18
				20	35
				40	78
				80	69
				120	84
		3.5	125	10	53
				20	54
				40	66
				80	55
				120	69
		3.8	125	10	53
				20	58
				40	33
				80	38
				120	58
		4.1	0	-	-
	Mid	0.15	130	10	32
				20	47
				40	58
				80	67
				120	67
		0.5	120	10	55
				20	54
				40	66
				80	64
				110	68
		1.0	124	10	53
				20	59
				40	59
				80	77
				110	91
		1.5	122	10	50
				20	65
				40	65
				80	87
				115	86
		2.0 m	123 cm	10 cm	63 cm/s
				20	80
				40	82
				80	93
				115	103
		2.5	125	10	65
				20	68
				40	87
				80	91
				115	108
		3.0	125	10	63
				20	79
				40	101
				80	103
				115	103
		3.5	123	10	49
				20	61
				40	68
				80	91
				115	73
		3.9	124	10	50
				20	41
				40	54
				80	64
				115	68
		4.1	0	-	-
	Outlet	0.2	140	10	36
				20	33
				40	62
				80	64
				120	63
		0.5	135	10	42
				20	53
				40	69
				80	65
				120	67
		1.0	130	10	50
				20	64
				40	67
				80	70
				120	69
		1.5	130	10	47
				20	52
				40	75
				80	78
				120	82
May 13	Inlet	0.15	105	10	2
				40	13
				80	18
		0.5	105	10	2
				20	10
				40	19
				80	21
		1.0	105	20	14
				40	16
				80	20
		1.5	110	10	22
				20	24
				40	36
				80	39
		2.0	123	10	35
				20	45
				40	46
				80	47
				100	56
		2.5	125	10	14
				20	54
				40	64
				80	68
				110	81
		2.0 m	130 cm	10 cm	56 cm/s
				20	63
				40	71
				80	80
				120	82
		2.5	132	10	64
				20	59
				40	85
				80	90
				120	87
		3.0	134	10	55
				20	63
				40	83
				80	87
				120	84
		3.5	133	10	35
				20	52
				40	78
				80	65
				120	64
		4.0	140	10	40
				20	48
				40	61
				80	70
				120	64
		4.25	0	-	-

Table A13. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 13 Cont'd	Inlet	3.0 m	135 cm	10 m	18 cm/s
				20	18
				40	83
				80	90
				120	95
		3.5	138	10	18
				20	56
				40	102
				80	105
				120	93
		3.9	135	20	25
				40	30
				80	51
				120	42
		4.3	0	-	-
	Mid	-0.15			
		0.2	115	10	18
				20	27
				40	38
				80	55
				100	43
		0.5	107	10	21
				20	37
				40	49
				100	61
		1.0	108	10	34
				20	43
				40	50
				80	62
		1.5	105	10	48
				20	47
				40	57
				80	63
		2.0	105	10	41
				20	55
				40	74
				80	79
		2.5	109	10	48
				20	53
				40	66
				80	84
				105	77
		3.0	108	10	45
				20	53
				40	65
				80	73
				105	75
		3.5	105	10	39
				20	51
				40	67
				80	73
		3.95 m	104 cm	10 cm	11 cm/s
				20	36
				40	45
				80	34
		4.25	0	-	-
	Outlet	0.25	120	20	24
				40	23
				80	46
				110	33
		0.75	110	10	44
				20	43
				40	51
				80	61
		1.25	115	20	44
				40	42
				80	62
				110	61
		1.75	115	10	44
				20	46
				40	58
				80	63
		2.25	122	20	46
				40	56
				80	66
				110	63
		2.75	115	10	53
				20	57
				40	61
				80	71
				110	63
		3.5		15	44
				40	57
				80	57
				110	54
		4.1	120	15	31
				40	39
				80	46
				110	42
		4.3	0	-	-
May 17	Inlet	0.15	84	10	3
				20	5
				40	2
				75	12
		0.50	70	20	3
				40	5
				75	18
				80	73
		0.75	73		
		1.0 m	84 cm	10 cm	11 cm/s
				20	9
				40	9
				60	15
				80	31
		1.25	90		
		1.5	96	20	19
				40	27
				60	28
				80	34
		1.75	100		
		2.0	104	10	23
				20	34
				40	43
				70	44
				90	50
		2.25	107		
		2.5	110	10	14
				20	37
				40	59
				60	58
				80	60
				100	68
		2.75	104		
		3.0	110	10	15
				20	27
				40	49
				70	62
				100	77
		3.25	115		
		3.5	117	20	42
				40	53
				70	60
				110	60
		3.75	110		
		4.0	110	10	28
				20	47
				40	48
				80	34
				110	48
		4.25	0	-	-
	Mid	-0.5			
		0.15	95	10	22
				20	27
				40	31
				60	28
				80	32

Table A13. Cont'd

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
		0.5 m	90 cm	10 cm	26 cm/s					80	54					40	39
				20	33			3.5 m	84 cm	10 cm	25 cm/s					70	43
				40	40					20	32					90	43
				60	41					40	44			2.0 m	98 cm	10 cm	35 cm/s
				80	41					60	46					20	34
		1.0	94	10	20					80	30					40	42
				20	26			4.0	85	10	16					70	46
				40	37					20	24					90	41
				60	43					40	30			2.5	100	10	33
				80	48					60	27					20	43
		1.25	85							80	21					40	45
		1.5	85	10	24			4.25	0	-	-					70	43
				20	31											90	41
				40	44		Outlet	0.25	98	10	27			3.0	100	10	26
				60	51					20	28					20	33
				80	51					40	32					40	38
		2.0	85	10	27					70	31					70	42
				20	40					90	20					90	40
				40	43			0.5	95	10	30			3.5	95	10	28
				60	56					20	37					20	29
				80	56					40	36					40	36
		2.5	90	10	26					70	N/M					70	39
				20	38					90	26					90	36
				40	49			1.0	95	10	28			4.0	105	10	25
				60	54					20	36					20	29
				80	54					40	38					40	26
		3.0	87	10	25					70	37					70	29
				20	35					90	37					90	27
				40	45			1.5	95	10	33			4.3	0	-	-
				60	54					20	35						

[1]Note: All measurements on ice.
n/c no current
n/m no measurement
B/E back eddy
*All shore measurements start at 0.00 m except where indicated.

Table A14. Growth in length summary by age class for Arctic grayling from Creek Mile 59.3, 1978 - 1981.

Year	Age Class	Sampling Period	n	Mean Length (mm)	Standard Deviation	Range (mm)
1978	0	I	117	14.1	1.1	11-17
	0	IV	34	55.8	10.4	38-84
	1	IV	7	130.4	7.1	120-140
	2	IV	1	214.0	-	-
	3	I	11	225.6	18.9	197-270
	3	IV	1	248.0	-	-
	4	I	25	260.9	25.4	218-299
	5	I	23	295.4	17.6	254-328
	6	I	6	293.8	37.4	230-332
1979	0	II	49	33.3	3.7	26-43
	0	III	37	54.2	6.4	38-68
	0	IV	10	52.3	5.4	47-62
	1	III	1	157.0	-	-
	1	IV	1	118.0	-	-
	2	II	1	171.0	-	-
	2	III	3	175.7	3.8	173-180
	3	I	9	225.3	17.4	197-255
	3	II	2	250.0	15.6	239-261
	4	I	15	255.6	10.4	236-272
	4	III	1	288.0	-	-
	5	I	10	301.2	15.5	280-325
	5	IV	1	302.0	-	-
	6	I	2	316.0	4.2	313-319
1980	0	II	24	47.3	4.6	38-58
	0	III	11	61.5	5.1	53-69
	0	IV	15	62.7	6.0	56-78
	2	I	1	162.0	-	-
	2	III	1	173.0	-	-
	3	I	29	206.0	20.4	177-244
	3	II	3	216.3	7.2	208-221
	3	III	1	214.0	-	-
	3	IV	3	210.7	4.6	208-216
	4	I	19	252.4	16.7	225-283
	4	IV	1	237.0	-	-
	5	I	14	273.5	20.6	234-301
	6	I	5	318.0	6.0	312-327
	7	I	1	334.0	-	-

Table A14 Cont'd

Year	Age Class	Sampling Period	n	Mean Length (mm)	Standard Deviation	Range (mm)
1981	2	I	12	135.6	14.6	123-172
	3	I	13	178.2	31.0	132-241
	4	I	34	232.4	14.4	203-265
	5	I	4	274.3	22.2	252-298

SAMPLING PERIOD INDEX

Sample Period	Study Year 1978	1979	1980	1981
I	May 14-June 9	May 17-June 4	May 4-23	May 15-20
II	N/A	July 10-11	July 13-14	N/A
III	N/A	August 19-20	August 17-18	N/A
IV	Sept 20-24	Sept 8-10	Sept 16-18	N/A

Table A15. Individual fish data from Creek Mile 59.3 Liard Highway Study 1978 to 1981.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Arctic grayling	15/05	240	120.	M4	3	
		222	110.	M5	3	
		231	110.	F5	4	
		226	100.	M4	4	
		224	100.	M4	3	
	16/05	237	150.	M4	-	
		275	240.	F4	-	
		268	240.	F4	4	
		218	100.	M4	4	
		300	270.	M4	5	
	17/05	305	280.	F5	5	
		287	220.	F5	5	
		254	150.	F5	5	
		216	90.	F3	3	
		300	270.	F5	6	
		327	356.	-	6	
		286	220.	-	5	
		276	200.	F4	6	
		197	60.	-	3	
		246	156.	-	4	
		284	210.	-	4	Tag-29338
		289	230.	-	4	Tag-29337
		285	220.	-	4	Tag-29339
		209	90.	M4	3	
	18/05	308	260.	M5	5	
		273	190.	F5	4	
		288	190.	M4	5	
	19/05	279	190.	M5	4	
		298	250.	F5	6	
		286	200.	M5	4	
		266	160.	M5	4	
	20/05	296	250.	M5	5	
		296	240.	M5	4	
		230	90.	F5	6	
		251	146.	F5	4	
		278	210.	F5	5	
		306	286.	M5	5	Tag-29340
		300	260.	-	5	Tag-29341
		328	320.	-	5	Tag-29342
		296	250.	M5	5	Tag-29343
		279	190.	M5	5	Tag-29344
	21/05	316	270.	F5	5	
		287	226.	M5	5	
		247	130.	F5	4	
		224	90.	F5	4	
		224	120.	M5	3	
		253	120.	-	4	
		225	90.	-	4	
		318	320.	M5	5	Tag-29348
		294	240.	M5	5	Tag-29347
		300	270.		5	Tag-29346
		266	170.		5	Tag-29345
		218	110.	M5	3	
		254	150.	F5	4	
		332	400.	M5	6	
		270	170.	M5	3	
	22/05	282	210.	F5	5	
		239	130.	-	-	
		299	270.	-	4	Tag-29350
	23/05	253	140.	M5	4	
	24/05	224	110.	M3	3	
		323	310.	F5	5	
	1978					
Arctic grayling	25/05	298	220.	F5	5	
		253	150.	F5	4	
		237	100.	-	3	
		297	230.	-	4	Tag-29349
		304	-	-	-	
	29/05	236	110.	F5	4	
	02/06	283	240.	F5	4	
	05/06	11(4)	-	-	0	
		12(4)	-	-	0	
		13(2)	-	-	0	
	06/06	248	160.	M5	3	
		12(1)	-	-	0	
		13(14)	-	-	0	
		14(19)	-	-	0	
		15(2)	-	-	0	
	08/06	13(4)	-	-	0	
		14(27)	-	-	0	
		15(32)	-	-	0	
		16(7)	-	-	0	
		17(1)	-	-	0	
	21/09	140	25.	F1	1	
		124	17.7	F1	1	
		136	21.5	M1	1	
		127	19.1	F1	1	
		54	1.2	0	0	
		57	1.3	0	0	
		61	1.8	0	0	
		65	1.9	0	0	
		67	2.			
		47	0.7	0	0	
		52	1.0	0	0	
		56	1.2	0	0	
		42	0.5	0	0	
		59	2.	0	0	
		66	2.4	0	0	
		54	1.2	0	0	
		76	3.7	0	0	
		62	2.1	0	0	
		66	2.4	0	0	
		53	1.4	0	0	
		43	0.6	0	0	
		73	3.6	0	0	
		53	1.2	0	0	
		52	1.0	0	0	
		49	0.9	0	0	
		47	0.7	0	0	
		41	0.4	0	0	
		38	2.7	0	0	
	22/09	69	2.7	0	0	
		84	5.4	0	0	
		59	1.5	0	0	
		51	1.1	0	0	
		54	1.2	0	0	
		49	0.9	0	0	
		50	1.0	0	0	
		45	0.9	0	0	
		52	1.3	0	0	
		52	1.1	0	0	
		120	16.0	-	1	
		135	16.0	-	1	
		131	21.1	-	1	
		248	160.	M2	3	
		214	95.	-	2	
		314	-	-	4	R/C 29350

Table A15. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Longnose sucker	18/05	316	340.	-	-	
	19/05	298	260.	M3		
		278	210.	M3		
		362	470.	F3		
		319	330.	M4		
		360	470.	F3		
		304	270.	M3		
		311	270.	M3		
		314	300.	F3		
	20/05	310	310.	M4		
		301	270.	M4		
		342	420.	F3		
		307	290.	F3		
	21/05	364	480.	F3		
		310	310.	F3		
		359	470.	F3		
		360	510.	F3		
		306	290.	F3		
		372	530.	F3		
		313	310.	M4		
		298	240.	M4		
		313	320.	M4		
		313	320.	M4		
		339	400.	F3		
		254	140.	M4		
		314	340.	M4		
		327	380.	M4		
		344	430.	F3		
		360	490.	F3		
		327	350.	M4		
		292	270.	M4		
		344	400.	F3		
		335	430.	F3		
		340	410.	F3		
		341	410.	M4		
	22/05	242	150.	F3		
		341	410.	F3		
		289	260.	M4		
		334	400.	F3		
	23/05	333	380.	F3		
		344	470.	F3		
		281	230.	M4		
		355	500.	F3		
		297	280.	F3		
		335	410.	F3		
		277	220.	F3		
		328	390.	F3		
		269	190.	M4		
		362	490.	F3		
		368	500.	F3		
		324	340.	M4		
		321	380.	F3		
		354	500.	F3		
		289	230.	M4		
	24/05	337	390.	M4		
		293	290.	F5		
		289	260.	M4		
		319	340.	M4		
		319	330.	F3		
Longnose sucker	25/05	312	330.	F3		
		286	240.	M4		
		333	380.	M4		
		248	110.	M2		
		355	510.	F3		
	26/05	321	330.	F3		
		256	170.	M4		
		295	260.	F3		
		255	180.	F3		
	05/06	284	220.	M4		
		26	0.1	-		
	21/09	108	15.2	-	2	
		109	14.3	-	2	
		115	15.0	-	3	
		99	10.1	-	2	
		92	8.4	-	2	
		94	9.4	-	2	
		126	23.0	-	3	
		109	11.2	-	3	
		98	10.2	-	2	
		107	13.0	-	-	
		111	13.8	-	-	
		92	9.2	-	2	
		97	9.3	-	2	
		77	5.7	-	2	
		102	11.3	-	2	
		85	7.3	-	1	
		65	3.4	-	1	
		49	1.2	0	0	
		47	1.2	0	0	
		49	1.3	0	0	
		44	1.0	0	0	
		47	1.1	0	0	
		39	0.6	0	0	
		42	0.7	0	0	
		34	0.4	0	0	
		39	0.6	0	0	
		43	0.8	0	0	
		35	0.4	0	0	
		38	0.6	0	0	
		35	0.3	0	0	
	22/09	44	0.9	0	0	
		38	0.7	0	0	
		44	1.1	0	0	
		53	1.5	0	0	
		35	0.4	0	0	
		39	0.6	0	0	
		51	1.4	0	0	
		29	0.2	0	0	
		41	0.7	0	0	
		44	0.9	0	0	
		44	0.9	0	0	
		46	1.1	0	0	
		44	0.8	0	0	
		42	0.7	0	0	
		41	0.6	0	0	
		41	0.7	0	0	
		42	0.7	0	0	
		41	0.6	0	0	
		39	0.5	0	0	
		33	0.2	0	0	
		36	0.4	0	0	

Table A15. Cont'd.

Species	Capture Date Day/No.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1978					
Longnose sucker	22/09	42	0.6	0	0	
		44	0.5	0	0	
		38	0.5	0	0	
White sucker	25/05	319	360.	M2	-	
	26/05	237	140.	M1	-	
Northern pike	02/06	337	260.	M5	3	
	1979					
Arctic grayling	17/05	217	90.	M3	3	
		260	170.	-	4	
		244	160.	-	4	
		290	270.	F4	5	
		216	100.	F1	3	
		218	100.	F1	3	
	19/05	321	380.	M3	5	
	20/05	298	270.	F4	5	Tag-29375
		319	340.	M4	5	Tag-29376
		262	180.	-	4	
		236	150.	F4	4	Tag-29377
	21/05	255	200.	M4	3	
		325	330.	M4	5	Tag-29381
		302	290.	M4	5	Tag-29382
		313	310.	M4	6	R/C-29341
		-	-	-	-	R/C-29348
		319	330.	-	6	Tag-29387
	23/05	225	100.	M4	3	Tag-29391
		280	190.	F3	5	
		248	140.	M4	3	
		272	200.	M3	4	
	24/05	246	-	M4	4	
		262	-	M4	4	
		292	240.	F4	5	
		287	210.	F4	5	
		298	240.	F5	5	
		197	100.	F4	3	
	25/05	226	120.	-	3	Tag-29398
		262	160.	-	4	Tag-29400
		247	170.	M4	4	
		258	180.	F4	4	
		262	200.	M5	4	
	26/05	268	160.	-	4	Tag-29411
	28/05	226	100.	-	3	
	29/05	261	130.	-	4	Tag-29423
	30/05	242	136.	F5	4	
	01/06	252	156.	-	4	
	10/07	239	145.	-	3	
		30(1)	0.2	0	0	
		34(2)	0.3-0.4	0	0	
		35(3)	0.3-0.4	0	0	
		36(1)	0.4	0	0	
		43(1)	0.7	0	0	
	11/07	26(1)	0.1	0	0	
		27(1)	0.1	0	0	
		28(2)	0.1	0	0	
		29(6)	0.1-0.2	0	0	
		30(1)	0.2	0	0	
		31(5)	0.2	0	0	
		32(3)	0.2-0.3	0	0	
		33(2)	0.2-0.3	0	0	
Arctic grayling	11/07	34(7)	0.2-0.3	0	0	
		35(6)	0.3-0.4	0	0	
		36(1)	0.4	0	0	
		37(2)	0.3-0.4	0	0	
		39(2)	0.4-0.5	0	0	
		41(2)	0.5-0.6	0	0	
		171	56.	M1	2	
		261	230.	M2	3	
	19/08	45	0.6	0	0	
		50	0.9	0	0	
		48	0.7	0	0	
		58	1.4	0	0	
		53	1.3	0	0	
		62	1.8	0	0	
		55	1.2	0	0	
		52	1.1	0	0	
		52	1.1	0	0	
		61	1.8	0	0	
		51	1.1	0	0	
		68	2.7	0	0	
		58	1.6	0	0	
		48	1.1	0	0	
		55	1.3	0	0	
		52	1.2	0	0	
		57	1.5	0	0	
		52	1.1	0	0	
		43	0.6	0	0	
		53	1.3	0	0	
		62	1.9	0	0	
	20/08	288	275.	M2	4	
		173	52.	M2	2	
		174	50.	M1	2	
		157	41.	F1	1	
		180	56.	M1	2	
		38	0.4	0	0	
		52	1.2	0	0	
		49	0.9	0	0	
		62	1.7	0	0	
		57	1.5	0	0	
		64	2.1	0	0	
		52	1.2	0	0	
		49	0.9	0	0	
		50	0.8	0	0	
		68	2.8	0	0	
		55	1.2	0	0	
		52	1.0	0	0	
		57	1.0	0	0	
		51	1.0	0	0	
		59	1.7	0	0	
		56	1.2	0	0	
	08/09	302	310.	-	5	
		62	2.0	0	0	
		58	1.5	0	0	
		58	1.6	0	0	
		48	0.9	0	0	
		47	0.8	0	0	
		48	0.9	0	0	
		49	1.0	0	0	
		49	0.8	0	0	
		55	1.4	0	0	
		118	16.6	0	0	
	10/09	49	0.5	0	0	

Table A15. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1979					
Longnose sucker	24/05	303	300.	M3		Tag-29392
		293	260.	M4		
	25/05	310	320.	M4		Tag-29397
		307	310.	M3		Tag-29399
		264	180.	M3		
		338	400.	F3		Tag-29394
		352	490.	F3		Tag-29395
		364	500.	F3		Tag-29396
	26/05	322	340.	M3		
		362	450.	F3		
		310	320.	M3		
		294	280.	M3		Tag-29406
		342	430.	-		Tag-29406
		361	480.	F3		Tag-29407
		306	270.	M3		Tag-29408
		291	250.	M3		
		295	266.	M3		
		366	550.	F3		Tag-29409
		309	320.	M3		
		290	260.	M3		
		315	330.	M3		Tag-29410
		316	300.	M3		
		342	440.	M3		
		262	180.	M3		
		291	260.	M3		Tag-29411
		311	300.	F3		
	27/05	367	580.	F3		Tag-29415
		280	230.	F3		
		337	380.	M4		
		316	326.	M3		Tag-29413
		311	320.	F3		
		282	220.	-		
		299	320.	M4		Tag-29414
		331	420.	F3		
		371	540.	F3		
		310	320.	F3		
	28/05	320	346.	-		Tag-29417
		373	570.	F3		Tag-29418
		355	500.	F3		
		335	400.	-		Tag-29419
		360	530.	F3		
		389	630.	F3		
		300	270.	-		
		336	480.	-		Tag-29426
		371	580.	-		Tag-29421
	29/05	302	270.	F3		
		272	220.	F3		
		305	310.	M3		
		312	320.	F3		Tag-39424
	30/05	293	250.	M4		
		305	300.	F3		Tag-29425
		317	310.	M4		
		309	300.	F3		
		277	220.	M4		Tag-29426
		333	385.	F3		
		294	280.	M4		
		296	290.	M4		
		265	200.	F3		
	31/05	247	150.	M3		
		320	350.	F4		Tag-29433
		286	260.	M4		Tag-29434
		308	370.	M4		Tag-29435
Longnose sucker	31/05	338	400.	F3		
		388	620.	F3		Tag-29436
	01/06	291	276.	M4		Tag-29439
		296	240.	M4		Tag-29440
		322	350.	M4		Tag-29441
	02/06	274	210.	M4		Tag-29445
		289	260.	M4		Tag-29446
		315	330.	M4		Tag-29447
		317	310.	M4		
		327	440.	F4		
		297	270.	F3		
	03/06	325	380.	M3		Tag-29448
		300	300.	F3		Tag-29450
		310	360.	F3		Tag-29449
		302	320.	M4		
		320	400.	F3		
		290	280.	F3		
		295	280.	M4		
	04/06	332	420.	F4		Tag-32752
		280	220.	M4		Tag-32799
		322	420.	F3		Tag-32800
	20/08	38	0.4	0	-	
Northern pike	09/09	285	164	M1	3	
		286	200.	M1	3	
	1980					
Arctic grayling	04/05	276	210.	M4	4	Tag-29446
		320	350.	M4	6	
		266	225.	-	5	Tag-29473
		240	140.	-	4	
		-	-	M3	4	
		-	-	F3	4	
		313	315.	-	6	
		281	245.	-	5	
	05/05	286	240.	M3	5	Tag-29458
		248	175.	-	4	Tag-29459
		247	160.	-	4	
		234	120.	-	5	
		281	250.	M3	4	
		250	155.	M3	4	
		236	140.	F3	4	
	06/05	225	135.	-	3	
		287	270.	F3	5	Tag-29463
		225	110.	M3	4	
		233	130.	M3	3	
		241	140.	F3	4	
		221	120.	M3	3	
	07/05	218	110.	F1	3	
		327	370.	M3	6	R/C-29341
		261	195.	M3	4	
		242	145.	M3	4	
		246	150.	F3	4	
		231	135.	F3	3	
	08/05	218	110.	F3	3	
		234	120.	M3	3	
		286	220.	F3	5	R/C-29345
		291	285.	F4	5	Tag-29470
		263	195.	M4	4	Tag-29471
	09/05	251	175.	F3	4	Tag-29499
		280	215.	-	5	Tag-29498

Table A15. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1980					
Arctic grayling	09/05	226	120.	-	3	
		248	150.	M3	4	
		202	75.	-	3	
		237	145.	M4	3	
	10/05	292	250.	F4	5	Tag-29490
		301	300.	F4	5	Tag-29489
	11/05	252	160.	F3	4	Tag-29482
		251	385.	M4	5	Tag-29481
	12/05	334	385.	M4	7	Tag-29478
		275	190.	M4	4	
		265	180.	F4	5	
		186	65.	F5	3	
		202	85.	F5	-	
		212	94.	M4	3	
	13/05	237	120.	-	5	
		188	70.	F1	3	
		183	56.	M5	3	
		177	56.	M5	3	
		203	82.	F1	3	
		230	118.	F4	4	
	14/05	244	132.	-	3	
		206	78.	M5	3	
		186	62.	M5	3	
	15/05	203	79.	-	3	
	16/05	207	90.	F5	3	
	17/05	183	55.	-	3	
		181	57.	-	3	
	18/05	178	57.	-	3	
		179	62.	-	3	
		185	61.	F1	3	
		214	95.	-	3	
		272	195.	-	5	Tag-29475
	19/05	283	270.	-	4	
		199	77.	-	3	
		312	357.	-	6	Tag-32651
	20/05	214	92.	-	3	
		318	340.	-	6	Tag-32652
	21/05	162	49.	-	2	
	13/07	46	0.9	0	0	
		44	0.8	0	0	
	14/07	38(1)	0.5	0	0	
		42(1)	1.1	0	0	
		43(3)	0.8-0.9	0	0	
		44(1)	0.8	0	0	
		45(2)	0.9-1.0	0	0	
		46(2)	1.0-1.1	0	0	
		47(2)	1.0-1.1	0	0	
		48(2)	1.1-1.2	0	0	
		49(1)	1.1	0	0	
		50(1)	1.4	0	0	
		52(3)	1.5	0	0	
		54(2)	1.5-1.7	0	0	
		58(1)	1.8	0	0	
		208	115.	M2	3	
		220	110.	M2	3	
		221	135.	M2	3	
	17/08	53(1)	1.4	0	0	
		54(1)	1.3	0	0	
		59(2)	1.4-1.6	0	0	
		61(1)	1.8	0	0	
		62(2)	1.6-1.9	0	0	
		64(1)	2.2	0	0	
Arctic grayling	17/08	66(1)	2.3	0	0	
		67(1)	2.4	0	0	
		69(1)	2.8	0	0	
	18/08	214	125.	M2	3	
		173	57.	F2	2	
	16/09	56(2)	1.6-1.9	0	0	
		57(2)	1.7	0	0	
		60(1)	2.1	0	0	
		62(2)	2.2	0	0	
		63(1)	2.6	0	0	
		64(1)	2.6	0	0	
		65(1)	2.7	0	0	
		68(1)	2.9	0	0	
	18/09	58	1.7	0	0	
		67	2.1	0	0	
		68	2.5	0	0	
		78	3.9	0	0	
		208	95.	M2	3	
		216	120.	F2	3	
		208	100.	-	3	
		237	155.	F2	4	
Longnose sucker	12/05	255	195.	M4		
	18/05	194	74.	-		
	18/09	152	50.	-		
	1981					
Arctic grayling	16/05	298	274.	F4	5	R/C-29470
		234	119.	M4	4	
		256	187.	F3	-	R/C-32653
		241	136.	M3	3	
		234	140.	-	4	
		227	114.	M3	4	
		223	111.	M3	4	
		218	96.	M3	4	
		223	106.	M3	4	
		226	104.	M3	-	
		214	97.	M3	-	
		198	71.	M3	3	
		197	78.	M3	3	
		222	103.	M3	-	
		186	60.	M3	3	
		203	74.	M3	4	
		246	147.	M3	4	
		245	141.	M3	4	
		228	121.	M3	4	
		242	130.	-	4	
	17/05	216	94.	-	4	
		243	155.	-	4	
		226	121.	F3	4	
		239	131.	M3	-	
		233	125.	F3	4	
		259	147.	-	-	
		230	113.	M3	4	
		265	172.	M3	4	
		223	103.	M4	4	
		242	125.	F3	-	
	18/05	247	146.	M3	4	
		234	105.	-	4	
		259	167.	F3	5	

Table A15. Cont'd.

Species	Capture Date Day/Mo.	Fork Length mm (n)	Weight g	Sexual Maturity	Age Class	Tag No. or Recapture No.
	1981					
Arctic grayling	18/05	288	238.	F3	5	
		252	176.	F4	5	
		216	98.	M3	4	
		244	122.	M3	4	
	19/05	230	126.	-	4	
		204	87.	-	4	
		196	81.	-	3	
		188	65.	-	3	
		178	65.	-	3	
		172	48.	-	2	
		149	23.	-	2	
		139	24.	-	-	
		138	22.	-	2	
		144	27.	-	2	
		143	28.	-	3	
		126	17.	-	2	
		137	21.	-	3	
		131	20.	-	2	
		143	24.	-	2	
		125	19.	-	2	
		228	122.	F4	4	
		252	160.	M4	4	
		228	119.	M3	4	
		237	127.	-	4	
		233	144.	F4	4	
		264	175.	M3	4	
		224	115.	F4	4	
		231	132.	F4	4	
		252	139.	F5	4	
	20/05	232	113.	M5	-	
		218	92.	F4	4	
		198	62.	-	3	
		125	16.	-	2	
		123	15.	-	2	
		128	19.	-	2	
		123	21.	-	2	
		174	55.	-	3	
		148	32.	-	3	
		132	20.	-	3	
Longnose sucker	19/05	326	395.	M3		R/C-29397
		311	350.	M3		
		364	550.	F3		
		345	470.	M3		
		280	275.	M3		
		290	290.	M3		
		294	280.	M4		
		284	255.	F3		
	20/05	324	400.	F3		
		342	460.	F3		
		334	420.	F3		
		312	320.	F3		
		348	530.	F3		R/C-29420

Table A16. In Culvert Velocity Measurements, Creek Mile 59.3 Liard Highway Study 1980.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity	Date	Site	Width	Depth	Depth @ Measure	Velocity
						July 13	Inlet	0.25 m	30 cm	12 cm	60 cm/s	July 13	Outlet	3.35 m	17 cm	7 cm	16 cm/s
May 13	Outlet	.1 m	0 cm	- cm	- cm/s					24	50			3.4	0	-	-
		.25	15	7	17			0.5	30	12	45						
		0.50	24	10	24					24	53						
				15	21			0.55	Rock Edge			After July 13 Cross Sectional Depths Only.					
				20	18			1.60	Rock Edge								
		0.75	25	7	21			1.75	10	6	28						
				10	23			2.0	10	6	49						
				15	22			2.25	12	6	71						
				20	19			2.5	24	9	35						
		1.0	20	8	5			2.75	34	14	40						
		1.25	14	7	11					28	29						
				11	13			3.0	30	12	61						
		1.5	13	7	9					24	59						
		1.75	12	7	9			3.25	0	-	-						
		2.0	17	7	11												
		2.25	9	7	14		Mid	0.15	24	10	59						
		2.5	11	7	11			0.35	35	14	56						
		2.75	14	7	12					28	66						
		3.0	33	7	16			.55	20	8	4						
				13	18					16	13						
				20	17			1.1	14	6	38						
				26	15			1.35	15	6	50						
		3.25	18	7	11			1.52	Rock Edge								
		3.45	0	-	-			1.9	Rock Edge								
								2.1	11	6	10						
	Mid Inlet	Ice Conditions						2.35	10	6	8						
								2.45	13	6	27						
								2.85	6	2	43						
May 16	Outlet	0.15	9	7	10			2.95	28	11	49						
		0.4	20	8	21			3.15	21	8	48						
				12	17					16	45						
				16	17			3.25	0	-	-						
		0.65	26	10	26												
				16	25		Outlet	0.2	20	8	18						
				21	21					16	12						
		0.9	20	8	14			0.5	28	11	23						
				12	15					22	22						
				16	13			1.0	29	11	14						
										23	20						
		1.15	8	7	11												
		1.40	5	5	4			1.3	19	8	12						
		1.65	6	6	8			1.6	19	8	13						
		1.90	7	7	9					16	13						
		2.15	5	5	10			1.85	21	8	21						
		2.40	9	7	10			2.10	20	8	22						
		2.65	11	7	3					16	23						
		2.9	27	11	7			2.35	23	9	20						
				22	3			2.6	19	8	23						
		3.15	33	13	14					16	22						
				20	15			2.85	38	15	22						
				26	14					30	29						
		3.35	0	-	-			3.10	37	15	25						
										30	34						
	Mid Inlet	Ice Conditions															

[1]NOTE: All measurements start at North side

Table A17. In-Culvert Velocity Measurements, Creek Mile 59.3 Liard Highway Study 1981.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 3	D/S culvert	0.05 m	20 cm	10 cm	32 cm/a
		0.6	30	12	16
		0.75	95	40	70
				80	36
		1.2	45	18	108
		1.5	85	34	40
				68	44
		1.9	73	29	16
				60	20
		2.4	65	26	15
		3.0	0	-	-
May 4	Inlet	0.5	5	3	105
		1.0	6	3	124
		1.25	8	4	140
		1.75	11	4	176
		2.25	14	4	182
		2.75	9	5	175
		3.25	15	10	244
		3.5	30	10	130
		3.75	0	-	-
	Mid	0.25	10		
		0.75	14	6	45
		1.25	17	7	96
		1.75	18	7	83
		2.25	22	9	115
		2.5	25	10	140
		2.75	25	10	188
		3.0	30	12	210
		3.25	28	12	200
		3.5	24	10	106
		3.6	20	8	39
		3.75	0	-	-
	Outlet	0.25	6	6	106
		0.5	10	6	118
		1.0	12	6	169
		1.5	12	6	172
		2.0	14	6	179
		2.5	14	6	190
		3.0	15	6	205
		3.25	17	7	205
		3.5	18	7	165
		3.65	15	7	165
		3.75	0	-	-
May 4	U/S 100 m	0.25	0		
		0.5	29	12	0
		0.6	30	12	1
		0.75	30	12	6
		1.0 m	30 cm	12 cm	16 cm/s
				24	14
		1.25	31	12	27
		1.5	31	12	37
				24	40
		1.75	31	12	47
				24	59
		2.0	33	12	51
		2.25	33	12	64
		2.5	34	13	65
		2.75	35	13	75
				28	77
		3.0	35	13	78
		3.25	35	13	85
				28	87
		3.5	35	13	87
		3.75	35	13	90
		4.0	35	13	83
		4.25	30	12	54
		4.75	23	10	25
		5.25	21	10	28
		5.75	16	6	24
		6.25	17	6	28
		7.75	13	6	16
		7.0	0	-	-
May 5	Inlet	0.25	27	11	145
		0.5	30	12	174
				24	178
		0.75	34	14	182
		0.1	35	14	186
				28	182
		1.25	36	14	186
				28	185
		1.5	37	15	182
		1.75	39	16	182
				21	180
		2.0	40	16	187
				32	178
		2.25	42	17	170
				34	168
		2.5	47	19	164
				38	152
		2.75	52	21	161
				42	143
		3.0	52	21	155
				42	138
		3.25	50	20	166
		3.4	60	20	166
		3.5	0	-	-
May 6	Inlet	0.25	30	12	144
		0.5	25	10	180
		0.75	28	11	180
		1.0	30	12	206
		1.25	29	12	191
		1.5	30	12	196
		1.75	33	13	193
		2.0	33	13	209
		2.25	34	14	191
		2.25	36	14	198
		2.75	41	16	198
		3.0	52	21	198
		3.25	50	20	201
		3.5	25	10	216
		3.65	25	10	242
		3.75	0	-	-
	Outlet	0.25			
		0.5	7	6	232
		0.75	12	6	255
		1.0	12	6	294
		1.25	12	6	322
		1.5	14	6	339
		1.75	13	6	353
		2.0	13	10	381
		2.25	26	23	381
		2.5	26	22	453
		2.74	27	24	417
		3.0	31	28	391
		3.25	23	13	386
		3.5	23	20	391
		3.75	23	20	216
		3.95	19	8	139

Table A17. Cont'd.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 6 cont'd	Outlet	4.0	0	-	-
May 7	Outlet	0.7			
		0.9 m	38 cm	17 cm	136 cm/s
		1.5	52	21	288
		2.0	48	45	304
		2.5	53	48	304
		3.0	53	48	268
		3.5	36	14	237
		3.75	12	8	206
		4.0	0	-	-
May 9	U/S 500 m	0.25	25	10	47
		0.5	85	17	31
				34	38
				68	58
		0.75	100	20	79
				40	82
				80	73
		1.0	102	20	98
				40	95
				80	73
		1.25	100	20	95
				40	85
				80	74
		1.75	91	18	84
				30	79
				72	64
		2.25	80	16	73
				32	60
				48	61
				64	61
		2.75	56	13	61
				26	57
				53	59
		3.25	50	12	45
				24	52
				48	55
		3.75	50	12	31
				24	47
				48	63
		4.25	62	25	31
		4.75	60	24	22
		5.25	47	17	18
		5.75	45	14	8
		6.25	0	-	-
May 10	U/S 500 m	0.25			
		0.5	22	10	31
		0.75	73	30	19

Table A17. Cont'd.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 11 Cont'd	Inlet	3.0 m	37 cm	10 cm	110 cm/s
				20	110
				35	96
		3.25	77	10	46
				20	47
				40	94
				60	87
		3.5	50	20	75
		3.9	0	-	-
	Outlet	0.25	20	8	49
		0.5	50	10	60
				20	82
				40	74
		0.75	70	10	42
				20	64
				40	91
				60	87
		1.0	40	10	103
				20	107
				35	113
		1.25	40	10	122
				20	126
				35	134
		1.5	43	10	87
				20	100
				35	118
		1.75	43	10	101
				20	107
				35	120
		2.0	72	10	9
				20	17
				40	96
				60	117
		2.25	50	10	85
				20	80
				40	98
		2.5	45	10	81
				20	95
				40	106
		2.75	83	10	41
				20	61
				40	87
				60	90
		3.0	80	10	57
				20	67
				40	96
				60	93
		3.25	63	10	35
				20	48
				40	54
		3.5 m	45 cm	10 cm	59 cm/s
				20	53
				40	33
		3.75	0	-	-
	U/S 500 m	0.25			
		0.5	45	18	23
		0.75	85	17	38
				34	40
				68	49
		1.25	80	16	74
				32	68
				64	64
		2.0	60	12	57
				24	67
		2.5	50	10	73
				20	72
				40	72
		3.25	40	16	71
		4.0	40	16	53
		4.75	40	16	43
		5.5	40	16	24
		6.0	0	-	-
May 13	U/S 500 m	0.25			
		0.5	40	16	29
		0.75	58	23	5
		1.0	64	27	66
		1.25	70	28	65
		1.5	72	28	74
		1.75	75	30	62
		2.0	76	30	58
		2.25	78	31	46
		2.5	87	35	49
		2.75	85	35	49
				65	54
				20	26
		3.0	100	40	46
		2.25	95	40	41
		3.5	55	25	44
		3.75	25	10	36
		4.0	0	-	-
May 14	Inlet	0.15			
		0.35	30	10	43
		0.5	50	10	61
				20	84
				40	85
		0.75	64	10	1
				40	64
				60	107
		1.0 m	69 cm	10 cm	14 cm/s
				20	28
				40	37
				60	104
		1.25	42	10	2
				20	36
				40	33
		1.75	25	10	83
				20	73
		2.0	50	10	50
				20	50
				40	50
		2.25	50	10	64
				20	62
				40	65
		2.5	57	10	13
				20	30
				40	111
		2.75	65	10	83
				20	104
				40	110
		3.0	77	10	57
				20	57
				40	75
				60	64
		3.25	60	10	65
				20	67
				50	56
		3.5	20	15	51
		3.7	0	-	-
	Mid	0.25	25	10	49
				20	43
		0.5	54	10	67
				20	83
				40	76
		0.8	75	10	82
				20	91
				40	77
				65	84
		1.0	40	10	65
				20	72
				35	75
		1.25	35	10	48
				20	48
				30	52
		1.5	63	10	32
				20	42

Table A17. Cont'd.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 14	Mid Cont'd			40	39			2.25 m	60 cm	10 cm	42 cm/s			1.25	55	22	62
				55	55					20	70			1.5	53	22	60
		1.75 m	65 cm	10 cm	2 cm/s					40	67			2.0	45	18	54
				20	43					55	78			2.5	37	15	52
				40	68			2.5	38	10	64			3.0	32	15	56
				60	83					20	80			3.5	30	12	54
		2.0	65	10	31					30	81			4.0	30	12	43
				20	35			2.75	52	10	69			4.5	30	12	37
				40	37					20	73			5.0	32	12	25
				60	64					40	80			5.5	38	15	12
		2.25	67	10	22			3.0	66	10	65			6.0	0	-	-
				20	35					20	79						
				40	47					40	84	May 19	Inlet	0.25			
				60	57					55	81			0.5	34	10	55
		2.5	50	10	27			3.25	60	10	62					20	71
				20	55					20	72					30	47
				40	89					40	77			0.75	56	10	1
		2.75	55	10	9			3.5	60	10	62					20	55
				20	34					20	72					30	72
				40	35					40	74					47	79
		3.0	75	10	B/E			3.5	40	10	46			1.0	35	10	28
				20	27					20	59					20	39
				40	34			3.75	0	-	-					30	54
				60	80									1.25	25	10	24
		3.25	70	10	56		U/S	0.25								20	22
				20	70		500 m	0.5	55	22	n/m			1.5	15	8	31
				40	88			0.75	55	22	29					10	1
				60	55			1.0	50	10	45					20	24
		3.5	45	10	35					20	60					30	32
				20	48					40	49			1.75	17	8	35
				40	60			1.25	50	20	64			2.0	24	10	46
		3.75		10	17			1.5	55	10	50					20	46
		3.8	0	-	-					20	62			2.25	27	10	38
										40	64					20	44
	Outlet	0.15						1.75	58	23	64			2.5	25	10	29
		0.25	11	6	8			2.0	60	23	59					20	47
		0.65	58	10	57			2.25	65	26	49			2.75	45	10	56
				20	72			2.5	65	26	43					20	59
				40	81			2.75	70	13	23					30	69
				55	90					26	32					40	63
		1.0	33	10	92					52	60			3.0	54	10	43
				25	109			3.0	80	20	33					20	69
		1.25	31	10	101					40	38					30	86
				25	103					60	59					40	86
		1.5	50	10	11			3.5	85	35	46					50	82
				20	45			4.0	82	35	30			3.25	53	10	56
				40	93			4.25	20	10	24					20	75
		1.75	30	10	102			4.4	0	-	-					35	90
				25	105											50	92
		2.0	31	10	89	May 16	U/S.	0.9						3.5	25	10	52
				25	99		500 m	1.0	55	22	61					20	15

Table A17. Cont'd.

Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity	Date	Site[1]	Width	Depth	Depth @ Measure	Velocity
May 19	Inlet	3.7	0	-	-					40	27					20	16
	Cont'd							3.0 m	63 cm	10 cm	24 cm/s					30	55
	Mid	0.15								20	27					40	62
		0.25	14							30	25			2.25 m	29 cm	9 cm	51 cm/s
		0.5	38	10	45					40	39					20	50
				20	62					50	55					25	48
				30	42					60	55			2.5	25	10	46
		0.75	54	10	54			3.25	62	10	22					20	48
				20	53					20	42				53	10	B/E
				30	63					40	30					20	5
				50	57					55	29					30	32
				60	54			3.5	38	10	34					45	44
		1.0	29	10	55					20	58			2.75	40	10	45
				20	54					30	37					20	50
				26	45			3.75	13	-	-					30	49
		1.25	25	10	30			3.9	0	-	-					37	48
				20	14									3.0	54	10	56
		1.5	50	10	19		Outlet	0.2	19	10	35					20	61
				20	32			0.4	45	10	43					30	62
				30	32					20	57					45	61
				40	44					30	62			3.25	55	10	35
		1.75	50	10	11					40	54					20	68
				20	34			0.75	44	10	47					35	68
				30	40					20	55					50	59
				40	39					30	64			3.5	25	10	33
		2.0	50	10	22					40	61					20	29
				20	26			1.0	22	10	73			3.65	0	-	-
				30	26					18	75						
				40	27				44	10	B/E		U/S	0.75			
		2.25	50	10	33					20	55			0.8	49	20	36
				20	32					35	56			1.1	46	18	62
				30	31			1.25	20	8	81			1.5	45	18	60
				40	32					17	84			2.0	35	14	61
		2.5	40	10	29			1.5	20	8	56			2.5	30	12	59
				20	43					17	76			3.0	22	8	55
				30	49			1.75	20	8	69			3.5	20	8	59
				37	50					17	83			4.0	20	8	37
		2.75	45	10	5			2.0	21	8	76			4.5	20	8	27
				20	24					17	74			5.0	30	12	24
				30	26				48	10	3			5.25	30	12	9
														5.5	0	-	-

[1]Note: All measurements on ice.
n/c no current
n/m no measurement
B/E back eddy
*All shore measurements start at 0.00 m except where indicated.

Photo 1. Creek Mile 48.9 - May 15, 1979. View of culvert inlet. Cleanup and channel protection measures not completed.

Photo 2. Creek Mile 48.9 - May 5, 1981. Wooden pole slope checks which replaced failed rock ditch checks. This design was also ineffective.

Photo 3. Creek Mile 48.9 - July 1984. Upstream view from culvert outlet.

Photo 4. Creek Mile 50.7 - May 1979. Downstream view of culvert installation at Creek Mile 50.7. Riprap placement and cleanup not completed. Downstream fish fence can be seen in the background.

Photo 5. Creek Mile 50.7 - Sept. 17, 1980. Roadside erosion along the Liard Highway as a result of rainfall. Note: failure of rock ditch checks in background.

Photo 6. Creek Mile 50.7 - Aug. 17, 1980. Downstream view towards culvert inlet. Heavy in-stream deposits of silt evident as a result of roadside erosion. Insufficient discharge 0.01 $m^3 \cdot s^{-1}$) to transport and remove materials from the stream.

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Photo 7. Creek Mile 50.7 - Aug. 1982. Roadside slopes with boulder checks installed - natural revegetation well underway.

Photo 8. Creek Mile 50.7 - July 1984. Upstream view. Note: vegetation well established on stream banks.

Photo 9. Creek Mile 51.9 - May 10, 1979. Extensive flooding within the construction zone. In-stream disturbance by construction equipment, washouts and erosion of unprotected channel contributed to increased suspended solids levels downstream.

Photo 10. Creek Mile 51.9 - May 24, 1979. Downstream view within diversion channel located at highway alignment. Note: proximity of slash and excavated materials to stream channel.

Photo 11. Creek Mile 51.9 - June 3, 1979. Aerial view of construction zone after flood waters receded. Note: deposits of excavated materials and slash, adjacent to stream channel. Note: visible stream turbidity downstream (photo right) of initial stream crossing (photo top and right) and abandoned bridge crossing (photo left).

Photo 12. Creek Mile 51.9 - Aug. 17, 1980. Upstream view from culvert inlet. Riprap material in place along channel. Discharge 0.01 $m^3 \cdot s^{-1}$.

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Photo 13. Creek Mile 59.3 - May 1978. View of stream section approximately 500 m upstream of highway alignment looking downstream. The stream is characterized by a gravel/boulder substrate with alternating pool and riffle areas in the immediate area.

Photo 14. Creek Mile 59.3 - May 1978. Sample of Arctic grayling captured in the fish fence at the alignment.

Photo 15. Creek Mile 59.3 - Sept. 9, 1979. View of culvert outlet and downstream slope stabilization. Note: the sharp bend in the new channel due to culvert alignment.

Photo 16. Creek Mile 59.3 - May 13, 1980. Upstream view towards culvert outlet. Note: intact ice layer within culvert. Stream flow occurred beneath the ice layer between the riprap material. Note: extremely low flow conditions during spring flood.

Photo 17. Creek Mile 59.3 - May 13, 1980. Side view of upstream fish fence.

Photo 18. Creek Mile 59.3 - May 10, 1980. Mature ovaries of typical three-year-old spawning grayling; fork length - 225 mm, weight - 120 g.

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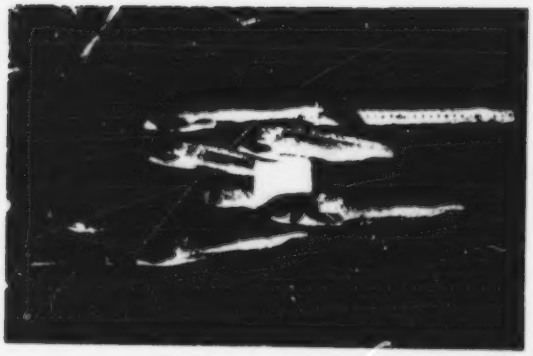

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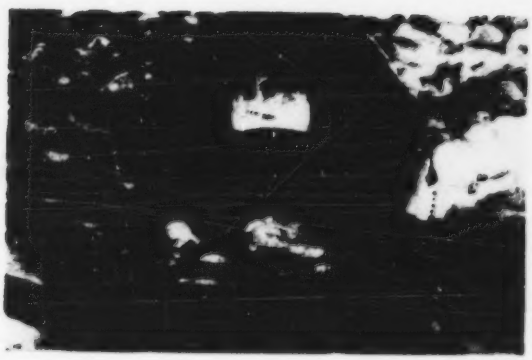

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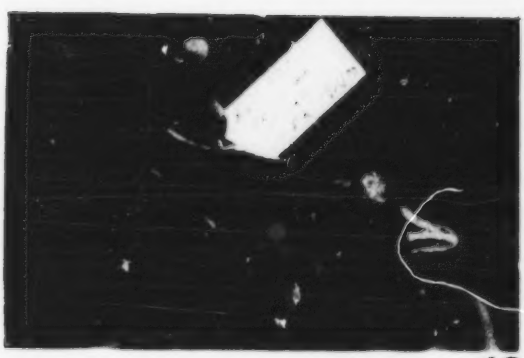

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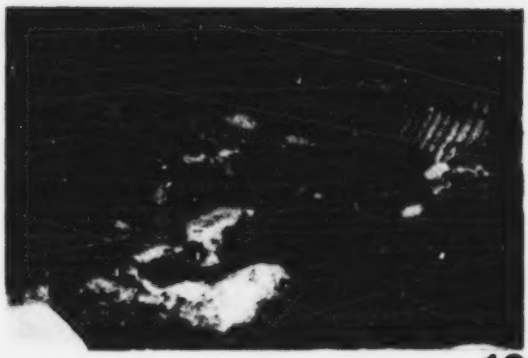
Photo 19. Creek Mile 59.3 - Sept. 17, 1980. Boulder riprap on culvert floor.

Photo 20. Creek Mile 59.3 - May 6, 1981. View of culvert outlet (discharge 2.3 $m^3 \cdot s^{-1}$). Water flow over approximately 1.5 m ice.

Photo 21. Creek Mile 59.3 - May 7, 1981. Upstream view of culvert outlet (discharge 3.6 $m^3 \cdot s^{-1}$). Stream flow has incised through the ice to the culvert floor. Some ice remains along culvert walls.

Photo 22. Creek Mile 59.3 - July 1984. Upstream view inside culvert. Note: riprap still in place.



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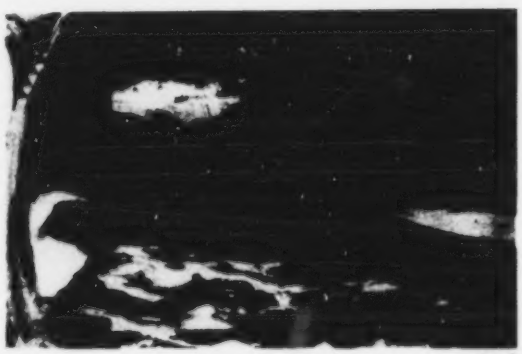

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